

Collective frame of reference as a driving force in technology development processes : the essential tension between path dependent and path breaking technology developments

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Collective frame of reference as a driving force in technology development processes

The essential tension between path dependent and path breaking technology developments



Cover page and above: Painting by Chris Chappell, Austin, Texas, USA, titled: "Highway Overpass", painted in 2004. The various routes shown in the painting metaphorically represent the technology paths that an organization can follow; hence it also shows the difficulty to 'break out' to a different path once the current path taken. Source: www.chrischappell.com

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**Collective frame of reference as a driving force in technology
development processes**

The essential tension between path dependent and path breaking
technology developments

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag
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Duijn, voor een commissie aangewezen door het
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door

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prof.dr.ir. J.E. van Aken

en

prof.dr.ir. M.C.D.P. Weggeman

Preface

The fact that you are reading this means that a journey has come to its end. It was a difficult journey - perhaps not only because it was literally difficult but rather because it was long and uncertain. Perhaps it was also difficult because of the question: Why would somebody with a career in industry and no particular academic ambitions spend a large part of his spare time writing a thesis? Every time I asked myself this question, especially in times of crisis, I formulated the answer surprisingly quickly: I have a deep desire to understand how technology is developed in firms and how it can be managed. The more profound reason is that I am convinced that a firm which develops technology more efficiently has a higher success rate than others. I realize that many other factors play an important role in the success of a firm, but I consider technology development as one of the most difficult in terms of planning and managing. I also believe, like many others, that technology and its development plays a very important role in product innovations, and is in general seen as the competitive edge of a firm. It is hard to beat a firm that consistently generates new technologies and possesses the knowledge to apply it properly. Technology Intensive Organizations (TIOs) are a growing group of organizations, as the propagation of technologies is still moving forward in global economic activities. There is a possible scenario that the majority of economical activities have a critical dependency on technology. Hence, I predict that technology development will be more important in the future and that firms have a desire to own unique technologies which give them competitive advantages. My prediction apparently goes against trends like 'open innovation', where firms open up their patent portfolio and are engaged in joint development projects, sometimes even with competitors. Still, my strong belief is that developments of core technologies are kept within the confinement of single entities, although partnerships and alliances are very important to spread the risks and to form a basis for further internal development. Having a specific and unique core technology allows maintaining a sustainable competitive advantage. It is also my belief that products are becoming more technology intensive and that firms are not capable of covering every technological aspect of the products they sell. It is at this point that I see a fit with open innovation, assuming that firms have to make "develop or buy" decisions concerning supporting technologies. In this perspective companies have to make very concise decisions about which technologies are, or will be, core technologies and require the firm's ownership to become successful in the target market.

In this thesis I do not present miraculous successes in technology developments and radical innovations resulting from these. Rather, what I intend to show is the daily battles are fought by technology developers, working very hard to make technological progress and hoping to see an opening in countless independently moving panels, allowing their creations to be brought to the world stage of business successes.

Is this thesis the end of that desire to know? The fact that you are reading this thesis also means that there is a journey ahead, may be still carrying a very similar question - hopefully for many years to come.

Some “New Technology Talk”

“There are two things you did forget. Really, totally forgot. First of all, you don’t know how difficult it is to bring new technology to the market. You simply don’t know! I do know, and you don’t! Secondly, Slood’s technology was not ready yet. I told you: It is like a pyramid up-side down. The lower part must be damn good to carry the rest. The fact was, it was not completed. Then one can say: Well, the missing part is 20% of 10 billion or may be it is the full 20 billion. Do you understand? That is what you totally forgot about.”¹

¹ Translated from an interview from the Dutch journalist Eric Smit [Smit, 2001] with Former Philips Board Member and Responsible for Philips Research, Roel Pieper, about a controversial technology venture based on a patent of an amateur inventor, Jan Slood, claiming a digital compression technique, capable of obtaining up to 2 million times data reduction. This affair got a lot of attention as Mr. Pieper first tried to ‘sell’ this technology within Philips. The researchers of the Philips’ research laboratories were very skeptical about this technology and rejected the validity of the invention on theoretical grounds. Some like to think that this was the main reason that Mr. Pieper left the Philips Corporation, in order to pursue this “100 Billion Dollar” opportunity and to become the CEO of **The Fifth Force Inc**, the firm that intended to exploit this technology. Jan Slood died shortly after Mr. Pieper resigned at Philips and the secrets behind his invention were never recovered and most likely literally “taken to the grave”. The Fifth Force was terminated shortly after that.

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This thesis would not exist, without the support of:

- Joan van Aken, who was able to keep me on track and motivate me by his persistent, and I would say unconditional, support. His fruitful and interesting discussions helped me greatly - not only to organize and improve my ideas, but also to spark my motivation.
- Matthieu Weggeman, who gave me the chance to do this work within the (former) Organization Sciences research group, despite the fact that a part-time PhD student comes with baggage.

Living in Canada made face-to-face interaction with Joan and Mathieu sparse, but when it did happen, they were very productive, joyful and motivating, and I would particularly like to thank them both for these sessions.

Furthermore I would like to thank staff and (former) colleagues at the TUE for their support and discussions, specifically Aarnout Brombacher, Marc de Vries, Joop Halman, Hans Berends, Hans van der Bij, Jan Peter Vos, Charmainne Lemmens, Stephan van Dijk, Irene Lammers, and Clarette Gispén.

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I would like to thank Martin Hynd for his proof reading and feedback on the technology development process. Also, John Wright helped me a great deal by sharing his experience with technology development in various technology intensive organizations. Maureen Searle and Dianne Barnes did a tremendous job in reviewing my thesis.

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Also a big thanks to my mother Ans and Thomas, for their help distributing this thesis, as well to my brother Willem, his wife Evelien, and my sister Maaïke, for providing their support.

I am very grateful to my wife Leila for her unconditional support. Especially during the difficult times she convinced me to carry on - if it wasn't for her, I would have never finished this thesis. The three joys of my life: Lisa, Esmee and Mick helped to keep me on track, especially in last months before the completion of this thesis and, not entirely without self-interest, it was regularly heard: "Dad, stop doing that other stuff! Finish your book!" This was always followed by; "We want to go to The Netherlands".

Nevertheless, it was my family in particular who allowed me to complete this work during our precious family time.

Waterloo, Ontario, Canada, spring 2010

Collective Frame of Reference in Technology Developments

In cherished memory of my father,
Kees

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Chapter 1: Introduction

*"If individuals can be motivated and directed without pecuniary incentives (and disincentives) and the exercise of authority, tremendous resource savings can ensue, and innovation processes can avoid the burdens of bureaucracy. Conversely, if a firm's culture and strategy does not align, it is likely to be unable to implement its strategy, especially strategies which involve innovation"*²

Chapter 1: Introduction

1.1 Motivation and Background

The motivation to initiate this study originated many years ago. As a research scientist at a research laboratory in a large firm dealing with electronics, many questions concerning the technology development process and its interaction with product development were encountered. The observation that technology development processes are apparently hard to manage made me curious about where this 'hard to manage' originated from. This curiosity was, and still is, an important motivator.

Later on, during the initial stages of this study, this motivation was further enhanced by the fact that a scan of literature showed that the management of technology development is often described to be one of the most important aspects of the competitive position of an organization, but not much about this process can be found in literature. Many articles have been written about innovation, both on success stories and on failures, but only a very few take into consideration the build up of knowledge and technologies as input for the innovation process. Some streams in literature denote this input as the 'Fuzzy Front-End' of the innovation process, as this input is highly uncertain in terms of usefulness for the innovation process. This stream assumes that the technology development process has uncertain outcomes and that the chances that the result is useful for application in products are low. Given this low success rate of the technology development process, it is interesting to understand how this process should be managed effectively³.

As a research scientist involved in the development of technologies, I was able to obtain an operational perspective. During this time in my career, I found it challenging to think of ways that enhance the generation of ideas that, once applied in a product, will give a discriminating effect on the market.

Observing the process of generating technology options and taking part in the process, revealed that several different processes led to new technologies. Several of these generated ideas which are constructive exponents of creative and interacting human

² D.J. Teece in [Teece 1996, p.206]

³ Some contributions in literature estimate that 95% of the products fail to provide economic return [e.g. Bergren & Nacher 2001 in Schilling 2008]. Although it is not certain how this relates to technology development, success rates of 20% are found. It is expected that the success rate of the actual technological ideas is much lower. For various justified and unjustified reasons these ideas do not make it to an implementation.

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brains, resulting in surprising solutions. At the same time, I also observed that suffering from the “not invented by me/us”-syndromes, ‘dysfunctional’ stubbornness and lacking the ability to cooperate, obstructed new solutions or sometimes actually generated new ones. These wanted and unwanted behaviours are all intriguing phenomena in the setting of technology developers at work.

Also intriguing were the interactions between the management and the operational levels. The tension between limiting spending on the one hand and an on-going search for a solution on the other is typical. In general it became clear that the average manager does not understand the average researcher. Normally they live in two quite different worlds, while there is a mutual dependency that obligates them to interact. As a result of those two interacting worlds the management of technology on the one hand and development of technology on the other, plays an import role in this research project.

I worked during this study in several Technology Intensive Organizations and this made it possible to observe the sequence of events of both the management and the

Dialogue box 1.1: Develop or Buy

In this study technology development projects are discussed. Of course, an organization does not necessarily need to develop (all) the technologies that are required to realize product innovation. It is assumed however that Technology Intensive Organizations need to look after their technology portfolio carefully and identify which technologies are unique and represent the most competitive advantage. These technologies are the core technologies that require special care. Given the importance of these technologies, it is assumed that these technologies require in-house development or, at least, are provided in an exclusive manner. The other required, but less unique, technologies can be acquired via licensing, or via ‘Open Innovation’. It is also argued that the impact on the organization is indifferent, whether a technology is developed in-house or acquired externally. The transfer of technology is painstaking and the organization still needs to learn how to work new external technology. In some aspects it may be more difficult to adopt external technology as in-house development implies higher levels of internal knowledge.

creation of technology from the inside. An obvious drawback is that these observations are subjective. This issue will be addressed specifically in the reflection section in Chapter 9 of this thesis.

1.2 Technology, Science, Knowledge, and Product Innovation

Based on the Bain's industrial organization economics [Bain 1956], Porter ranks technological change as one of the principal drivers of competition in industries [Porter

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1983]. There is some confusion as to what is meant by technology development, but many (see, e.g., [Berry & Taggart 1994]) make a distinction between the generation and testing of new technical ideas and knowledge on the one hand and the actual application of these ideas and knowledge in New Product Development (NPD) on the other. Cooper [Cooper 2006] argues that technology development projects create the foundation or platform for new products and new processes and thus are vital for the prosperity of the modern corporation. Consequently, technology development is an important issue for Technology Intensive Organizations and, as pointed out in the previous section, it is very difficult to manage this process well.

Given the variety in definitions and the not always clear distinctions between them, it seems to be appropriate to give not only a description of Technology, but also its relation to entities like Scientific Discovery and Product Innovation or New Product Development. The variety of interpretations and meanings of these entities is confusing and finding a definition of technology in literature is troublesome as many interpretations, nuances, specific meanings and relationships are found. Rather than discussing all of these definitions and interpretations it makes more sense to give a definition of technology that fits the context of this thesis.

There are two primary relationships for this research. Given the nature of activities which are typically performed at an industrial research lab, it is justified to define technology as being linked to the:

1. Scientific principles and/or empirical principles, and the functions that can be deduced from these principles.
2. Functions of a product or a process that fulfil a certain need in society.

Consequently, every function of a product is considered to be linked to one or more technologies. This implies that a product can be subdivided into different functions and that every function originates from a technology that is based on a scientific and/or an empirical principle.

Many older technologies are not so much based on scientific principles, but more on empirical principles. For example the first planes were developed on the basis of 'trial and error' and not on a framework of scientific principles. Many years after the first flight, 'science' did catch up with the achieved technology level and provided a scientific framework. This framework allowed for more technological progress that brought aviation where it is today. It can be seen as a trend that new technologies which are based on empirical principles become rare, and therefore it can be said that modern technologies are virtually always based on scientific principles. However, this does not imply that the latest technology is always linked to recent scientific discoveries, actually on the contrary; more often the technologies are based on scientific principles that are quite old. These scientific principles are not necessarily linked to applied science, but can be linked to historical theoretical scientific achievements.

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An example is the advanced transistor technology that is based on Quantum Mechanical principles. Surprisingly, Quantum Mechanics, which is often seen as an example of theoretical science that stands distant from everyday life, but is now entering the average home in the form of even more powerful PCs. Fundamentally this shows that it is difficult to consider a rigid distinction between applied and theoretical science; as theoretical science sometimes becomes applied science and leads to new technologies.

Given the two elements that are predominately - either implicitly or explicitly - present in the context of the study: science and function, and considering modern technology development without considering empirical principles, the following definition is adopted:

Technology is an artefact, which is based on scientific principles, and which provides a certain function that fulfils a need in society.

The scientific principles in the definition refer directly to science, but on one hand it should be noted that only a subset of the scientific principles (as a part of 'science') is suitable for the creation of an artefact. On the other hand, it is not said that science (in particular scientific discovery) is fully independent of technological needs that come forward out of a required function in society. For example, scientific programs have been and still are initiated to enable technologies which contribute to the reduction of greenhouse gases. However, it is not said that the function is well defined by the society - in some cases technology brings artefacts forward that fulfil a latent need. The term 'artefact' implies that technology is always related to something 'man-made', although it is not necessarily confined to physical artefacts.

In both domains, scientific discovery and product innovation, knowledge is considered a relevant aspect. Knowledge intertwines with the definition of technology in at least three aspects. The first aspect is that scientific principles are based on (scientific) knowledge, which is generated by observations, experiments and theoretical principles. The second aspect is that knowledge needs to be generated to obtain a construct. A construct embodies the scientific knowledge but in order to create a construct, practical knowledge or 'know-how' is necessary.

The third aspect is that knowledge is related to 'knowing which function needs to be fulfilled in society'. This is considered as 'soft' knowledge, but not irrelevant as, by definition, technology intends to serve a certain purpose in a social context.

In the context of this study, knowledge is defined as justified true belief, which is discussed in the recent paper of Nonaka and Krogh [Nonaka & Krogh 2009, p.639]. Berends and Weggeman provided an overview of the spectrum of different knowledge definitions and argued that a choice for a certain definition can be made as long as the

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implications of this choice are well understood [Berends & Weggeman 2002]. The choice for knowledge as ‘justified true belief’ is justified by two reference points; it connects to the notion of the scientific beliefs as described by, e.g., Polanyi [Polanyi 1950], and to the notion that beliefs play a role in technology development as described by e.g., Garud and Rappa [Garud & Rappa 1994]. Not disqualifying other definitions of knowledge, I hold that this definition fits well for the context of this research.

The relationship with product and product development or innovation is illustrated by the following definition of product. A broad definition of product is meant here: it can be a physical product but also a non-physical product (e.g. software or services).

A product is an artefact with a certain form, fit and function, which comprises one or more product technologies, and which is created by utilizing one or more process technologies and satisfies a certain need in society.

The use of technology is not only related to the functionality of the product but can also be related to production technologies (e.g., refinery technology to create gasoline).

In some cases it may be challenging to relate the functionality of a product to a certain technology. In general it can be accomplished, although in some cases the relationship is vague. An example is the product ‘online banking’, which is a product (service) that is offered to enable customers to do their banking via the internet. The main technology this service is deriving its functionality from is Information Technology (IT). This is a little vague as it is not directly clear how this will determine the functionality, but it can be made plausible that the combination of IT hardware technologies (e.g. servers) and IT software technology (e.g. network protocols) in the end determine the functionality of this product.

The adoption of the relationship between products and technologies will relate the product innovation to the availability of technologies in a logical fashion. In this perspective, product innovation is related to technology but new technology is not always conditional to product innovation. Quite often product innovation is based on existing functionality and therefore existing technologies are used and innovation is established by altering the design parameters. A novel technology, which offers a new functionality, can give rise to a new product that is highly innovative because of this new functionality and because it potentially fulfils a unique function in society. However, the use of new technologies does not necessarily mean that product innovation is realized. For example, a new process based on a new technology can be used to produce exactly the same product (or at least for the end user unnoticeable different). Product innovation can also be realized through a new combination of existing technologies. [e.g., Haragon 2003] In this perspective technology is seen as the carrier of functionality in a product and/or process and a single product can be compiled of several different technologies, that each represents a certain ‘useful’ function in society.

Consequently, the framework of technology is positioned between the entities: scientific discovery and product innovation, and this in the context of bringing functionality to society. Within this framework, the purpose of this study is to contribute to the knowledge about technology development and the technology development process.

1.3 Technology development

Technology Intensive Organizations develop products that derive their main functionality and/or creation from one or more technologies. This implies that the technology options which are available within a firm contribute to the competitive position of that firm [e.g. Edge 1995, Cooper 2006]. However, the development of these options are painstaking and extend over a long period of time and, in general, are longer than the two to five years timeframe that is attached to the general cooperate operations.

Obviously, technology can also be acquired externally, but this comes with the risk that the technology is not unique enough to provide a competitive advantage [e.g., Shanklin & Ryans 1984, p.108]. Even so, the implementation of an externally acquired new technology is still painstaking, risky, and both time and resource consuming. These difficulties imply that the risk of overlooking technological shortcomings, and therewith the deterioration of competitive position of a firm for the longer term is not imaginary. Despite the fact that technology plays a crucial role in product development, it's development process seems to be underexposed in the literature on New Product Development (NPD) and product innovation. In literature, technology is often seen as either a given and available asset or as a fuzzy and unpredictable process prior to NPD. Indeed, the outcome of technology development projects is uncertain, but this does not necessarily mean that the processes within the development are undefined, defocused or fuzzy. On the contrary, research groups working on technology development are focused on predetermined goals and in general follow a very well defined course of action most of the time. Having said this, the actual uncertainty comes mainly from the unpredictability that is associated with searching and following existing and new paths. So the goals are clear and known but the path to reach the goals is not necessarily known.

The fact that the search for new technology can be described as “following paths in an unknown landscape of possibilities” is not an ad hoc assumption. This idea is brought forward in many bodies of literature: Scientific Discovery [Kuhn 1972], [Klahr & Simon 1999] Economics [Nelson & Winter 1981], Organizational Change [Van de Ven & Poole 1995] and Cognition [Garud & Rappa 1999].

This path dependency suggests that once a certain direction has been chosen, there are forces that keep the development along the path. On a positive note, it also suggests

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that there is some visibility on which challenges will be met and that progress is related in a logical fashion to what has been done before. On a negative note however, path dependency suggests that it will cost additional effort to change the course significantly, or follow an alternative path.

In general, path dependency is brought in connection with organizational inertia, stickiness and inflexibility [see e.g., Sydow 2009]. The definition of path dependency is based on two entries found in literature that seem to be particularly relevant for this thesis.

Teece refers to the definition of Dosi, which has an evolutionary economical context and where path dependency is directly coupled to technology paradigms: “A technology paradigm is a pattern of solutions to selected technical problems, which derives from certain engineering relationships”. This definition relates more or less directly to the problem solving process [Teece 1996, Dosi 1982].

Garud and Karnoe define more generic path dependency as: “a sequence of events constituting a self-reinforcing process that unfolds into one of several potential states”, [Garud & Karnoe 2001].

Both definitions are relevant for this research, and therefore the path dependency for technology developments in the organization is defined as follows:

Technology path dependency is a self-reinforced organizational process that unfolds into a pattern of sequential and interrelated solutions to selected technical problems.

An important aspect to this dependency is how the organization operates while following a path. A more interesting question could also be: What happens if an organization realizes that following the current path is not sufficient enough to reach the goals that have been set?

Also vital is the role of individual contributions while following the path or changing to another path. In the usual course of events, technology development is a group process in which several individual players participate, and it is expected that any change in the course of the group has an individual actor. This implies that the roles of the individual group members cannot be overlooked while observing the path that is followed by a group in an attempt to find new technological solutions. ‘Following’ a path towards a solution implies that a problem is solvable and that the new technology is feasible. Following a path also provides some level of certainty that a solution can be found and that the problems that need to be solved are similar to problems that were solved in the past. This allows for a higher degree of planning for resources, costs and lead times. ‘Leaving’ the path means in general that several unfamiliar problems need to be solved and that unknown efforts have to be spent to obtain an outcome. Effectively the uncertainty is much higher, and does not allow for much planning. In the context of

technology development, either following the path or leaving the path means that technical and/or theoretical problems need to be overcome before a new technology is proven to be feasible and suitable to be applied in a product.

Consequently following a path towards a new technological solution requires problem solving capability in the group members. Newell and Simon published an impressive volume on the human problem solving process, which deals with processes at an individual level [Newell & Simon 1972]. Given the fact that researchers interact, it is interesting to see how the individual problem solvers interact and cooperate to find a solution. In the following sections of this paragraph, several aspects of technology development will be presented and discussed.

1.4 Objectives of the study

The objective of the study is to obtain an understanding of the drivers of technological developments in the organization. As technology is considered to be very important for feeding new product development, especially for Technology Intensive Organizations, the development of technology within the organization is a very important process. This study intends to contribute to the understanding of:

- The technology development process: The technology development process itself is sparsely described in literature. One of the most likely reasons is that technology is multi-faceted and not uniformly defined. An objective of this study is to give a clearer picture of technology development in organizations and the relationships to product development.
- The driving forces for the technology development process: So far in the New Product Development literature, technology is considered as a given input and that access is assumed. This may be true in main stream New Product Development, where very gradual changes are made with respect to the technologies that are applied, but in cases where the required changes are more radical, new technologies are required to develop a new product. The objective of this study is to identify the factors that drive technology developments.
- The organizational changes associated with technology development: The development of a new technology is a strategic choice and requires changes in the organization. For example, the knowledge base of the organization is required to change in order to master the new technology. The objective of this study is to study how these changes are implemented.
- The interactions between the management level and the technology developer level: Technology development requires many decisions on several levels in the organization. The decision to develop new technologies not only requires allocation of resources by the management, it also needs technical decision making at the level of the technology developers. Over the course of the

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technology development process the interactions between the management level and the developers' level are so intense and frequent that it requires special attention. An objective of this study is to observe the interactions between the management and developer level.

- The management of the technology development process: As an organizational process, technology development needs to be managed and accommodated. This study intends to provide guidelines for the management of this complex process.

To create a foundation of the objectives above, a framework will be created that will put the technology development process in a theoretical and practical perspective, including the driving forces, the related interactions between the management- and developer level and the relevant management techniques.

1.5 Research Questions

As discussed previously, technology developments are considered to exhibit a path dependency. This dependency and the anticipated necessity to change paths at times give rise to the research questions of this thesis.

One of the main research questions is about what technology development is and what the characteristics are in comparison with Scientific Discovery and New Product Development. In order to understand what path dependency means and what the forces are to follow or leave a path, the technology development process itself needs more understanding.

Research Question 1:

What are the characteristics of the technology development process in general and in comparison to the Scientific Discovery process and the New Product Development process?

Technology developments, which follow a certain path, progress in a state of equilibrium require only evolutionary changes and have a limited impact on the organization. However, technology developments which require a change of path are considered to be much more radical to the organization. A path change requires the build up of a new knowledge base and in some cases a new organization and new resources.

There are at least five aspects that need to be understood about a path change. Firstly, it is important to understand how the organization resists against a path change. Secondly, how is a path change initiated, and thirdly, how is the organization adapting to this path change. These three aspects are covered in the second research question.

Research Question 2:

What are the processes and drivers at several levels in the organization prior, during and after a technology path change?

The fourth aspect is finding the alternative path. By definition there is limited knowledge available about alternative technology paths which affect the decision making related to choosing an alternative technology path.

Research Question 3:

How are alternative technology-paths identified, evaluated and selected?

The fifth aspect is related to the required changes that are necessary to migrate to the alternative technology path. The change in the organization that is required can be very significant as a new knowledge base has to be built up. Obviously, this is knowledge about the technology itself but knowledge about managing the new technology might also be required. Managing the change is of great importance and will challenge the current operations.

Research Question 4:

What are effective management techniques to manage the decisions related to technology path change and the associated organizational changes?

The answers to these research questions carry many aspects and can be approached in many different ways. Obviously, not all aspects can be covered in the scope of this study, but at least an attempt will be made to cover the most important factors that play a role in technological change within Technology Intensive Organizations.

1.6 Research Strategy, Methodology & Method

1.6.1 Research Strategy

The next step is to choose a sufficient research strategy and one or more methodologies in order to realize the research goals. Although Gummesson [Gummesson 2000], a pronounced advocate of qualitative research, makes clear that the a priori selection of a research strategy endangers the objective view of a researcher. Therefore it makes sense to choose a certain research strategy as a starting point and to keep in mind that other research strategies can be applied that may provide a novel view on matters.

Following Creswell [Creswell 1994], and given the framework of the study, a qualitative research strategy seems to be a logical choice. Creswell proposes to base the selection of the research strategy on five assumptions; the ontological, epistemological, axiological, rhetorical, and methodological assumption. Creswell states that the

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qualitative research strategy assumes that reality is subjective (ontological assumption), the researcher interacts with that what is researched (epistemological assumption), the researcher is value-laden and biased (axiological assumption), the language of research is not-deterministic (Rhetorical assumption) and the process of research is inductive, emerging and context bound (Methodological assumption). These assumptions fit with the framework of this study, supporting the conclusion to adopt the qualitative research strategy.

Another view on the reason to choose between the qualitative or quantitative research strategies is that the use of quantitative research needs a very well defined framework of parameters in order to obtain a meaningful measure. However, some phenomena are lacking such a framework and qualitative research need to be done to map the relevant parameters. Again, given the framework, quantitative research seems to be too premature for this study.

Symon and Cassell [Symon & Cassell 1998] suggest in their introductory chapter that the qualitative research strategy, in contrast to the quantitative research strategy, allows intrinsically more freedom to elaborate on new theories. It should also allow taking a view into account, based on personal experience. These features of the qualitative research strategy seem to be very tempting because they imply a large degree of freedom for the researcher.

However, limited accountability and reproducibility of the research results are pitfalls of this approach. To overcome this, Miles & Huberman⁴ [Miles and Hubermann 1994] suggest coupling the qualitative research strategy to a set of validated and verifiable methods, leading to analogue conclusions when applied by others. The question arises whether these methods exists. There are many qualitative methodologies like Grounded Theory, Action Research, Case Study Research Functional Analyses, and Template Approach. However, within these methods many different approaches are described.

1.6.2 Methodology

One approach to deal with the non-uniformity of methods is to follow methodological approaches that have been described in literature and provide accountability for every change within the method or shifting to another method. To illustrate this, the first case study which will be described later on, illustrates how the initial stage of the grounded theory has been used to find a sensitizing concept which embodies the phenomena of interest. A review revealed that, in many bodies of literature, similar phenomena are described. From this it can be concluded that a wide, exploratory study in the spirit of the Grounded Theory is not necessary, and that a more structured descriptive methodology can be applied.

⁴ Miles and Huberman consider themselves as positivist with a 'soft nose' to indicate that they acknowledge the existence of social phenomena in the objective world. In the context of this reference they take the opportunity to make a remark how the qualitative paradigm should be adopted.

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The (planned) field research consists of a mix of case studies following technology development projects by participating observations, and non-participating observations. In this perspective, the research methodology resembles action research as described by Gummesson [Gummesson 2000]. However, the question arises whether it is suitable when the researcher is an employee instead of a consultant.

Although Gummesson acknowledges that the position of researcher/employee is more complicated in the sense that the position of the employee in the hierarchy of the firm determines its access to strategic decision processes, it can be useful when the effect of strategic decisions on an operational level are studied. The latter is more or less the case in this research. This participant/observant role is not new - for example Roy described the time when he was a working in a steel shop as a radiant-drill worker [Roy 1952, 1954].

The technological change is studied on a level of technology developers, who do not necessarily have access to strategic decision processes. However, to study how decisions on technological change disseminate from the strategic management level to the level of technology developers, I had obtained access to the strategic management level in the function of facilitator of strategic decision processes. This is an additional position aside the technology developer position. This auxiliary position, which can be seen as an in-house consultant, opens the way to action research in the role of change agent.

1.6.3 Method

Gummesson [Gummesson 2000] created a qualitative methodology for researcher/consultant or researcher/employee combinations and he pointed out that case studies are used as a logical consequence of applying action research to organizations. He is less clear about the research methods to use and therewith he leaves open whether the researcher should apply a structured or unstructured approach.

Questions like how the case studies are set up, how (qualitative and/or quantitative) data is collected and analyzed and whether the research (in the end) should lead to a theory or not are not answered. These aspects and related methods are described by Miles and Huberman on structured vs. unstructured, data collection and analysis [Miles & Huberman 1994], by Yin on case study design [Yin 1999] and by Glaser and Strauss on development of theories [Glaser & Strauss 1967].

Miles and Huberman indicate that there is a continuum from unstructured to structured and they suggest that the researcher should find a position on this scale that is appropriate for the research that is required. For example, a phenomenon that is known in literature in a certain context and which is studied in another context can be researched with a structured qualitative method suggested by Miles and Huberman.

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Phenomena which are not well described or are even unknown to exist need a more unstructured approach like Grounded Theory or an even more unstructured approach like unbiased observations. For phenomena related to technological change, which is the subject of this study, it falls somewhere in the middle. In literature, enough related phenomena are found that are related to technological change in a context similar to the one of this study. So although the concept itself is not described, there is some rationale to choose a somewhat more structured qualitative method.

Miles and Huberman suggest a structured approach if research is done at multiple sites⁵. In the framework of this study, this is indeed the case. King in Symon and Cassell [King 1998], suggests that applying structure implies that choices are made and that this can have large influence on the outcomes of the study. Also the application of a conceptual framework which defines the main area of study assumes that the researcher has certain 'pre-knowledge' of the relevant phenomena. This causes a dilemma: on the one hand the researcher structures the research of a certain phenomenon by assuming certain relationships, while on the other hand these relationships are the subject of study. The question arises on what basis these choices can be made.

Gummesson introduces the principle of pre-understanding to indicate that a researcher can suspect that a certain relationship can exist without having a full understanding or knowledge about the magnitude and background of that relationship. On the basis of this pre-understanding, a researcher may draw up a conceptual framework. This framework remains tricky because relationships or phenomena which are outside the imagination of the researcher are automatically overlooked and lead to devaluation of the research results.

In conclusion, it becomes clear that, on the one hand, the researcher needs to keep an open mind and a critical stand regarding the initially chosen structure, while, on the other hand, this structure can help to focus on the relevant data and organize the collection of data.

For this study a conceptual framework will be drawn up in order to structure the qualitative research. To prevent influential factors from being overlooked, a regular evaluation of the results by means of member checks is planned.

The set up and design of case studies is well described by Yin. Yin typified several possible designs and emphasized the notion that the validity and reliability are essential to consider in the case study design. The design of the case studies in this project will be characterised by multiple viewing points and multiple levels.

One question remains: Should a theory be developed or will the research be limited by the description of a certain practice. It is my belief that the formulation of theory will contribute to the mapping of the complex field of organizational science. By

⁵ According to Miles and Huberman a 'site' is equivalent to a 'case'

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developing theories, other researchers are invited to test these theories and confirm, replace or sharpen them.

However, in practice it will be very difficult to build a theory that covers a significant part of organizational science because of the virtually limitless variables. Although this can be discouraging, an attempt will be made to contribute to the forming of theories from organizational research.

A more structured approach is the 'fusion' approach of Eisenhardt [Eisenhardt 1989a]. Eisenhardt combines the principles of grounded theory from Glaser and Strauss, the principles of qualitative data analysis from Miles and Huberman and the principles of case study research from Yin. The steps defined by Eisenhardt are followed in this study and an implementation of the step wise approach is given below.

Step 1: Study Setup

The first step is to formulate the research questions (see section 1.5 of this Chapter). The research questions should apply focus to the research area. In this case, the driving forces behind technology development in Technology Intensive Organizations are studied. Eisenhardt indicated that the formulation of an a priori construct might help to focus on the acquisition of the right data. The construct is related to the discussion above on the extent of structure that should be applied beforehand.

In this study the previously discussed path dependency can be seen as an a priori construct: it is expected that the path dependency exists and assumes that it influences the direction of the strategic decisions. The conceptual framework as suggested by Miles and Huberman can also be seen as an a priori construct.

In this perspective a conceptual framework is created on the basis of a set of hypothetical assumptions. These assumptions can change during the project by finding evidence either in literature or by field research. This implies that the conceptual framework may alter, and consequently the course of action may alter during the research process. It makes sense to define an initial conceptual framework that captures the focus of the study and places the research questions in a context. This is an a priori conceptual framework which is expected to be changed and become more accurate during the course of the study.

The a priori assumptions on which the conceptual framework is based are:

- Strategic decisions related to technology development in Technology Intensive Organizations are subject to the paradigm theory of Kuhn [Kuhn 1970].
- Consequently, the decision processes related to the technology development process are subject to path dependencies.
- The path dependency comprises the competencies, the technologies, the past history and past strategies of the organization.

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- The technology development process takes place at two levels in the organization; the management level, controlling the process by deciding on resource allocation (time and money) and at the (technology) developer level, deciding on the course of action of the development process.

Step 2: Selecting cases

In this project the case studies are mainly selected based on the access of the researcher to the processes. Because the researcher is professionally involved in Technology development, it is logical to select this field and the organization implementing the technology as object of study.

The strategic process of technology development is examined based on three case studies. The first study observes the early phases of the technology development process, observing the basic research on new properties of a certain material and the initial steps to use these properties in new technology. The technology development process in this first case is categorized as 'material science', while the technological application is related to field of 'display technologies'. The organization, an Industrial Research Laboratory, falls in the category of Technology Intensive Organizations, with an emphasis on generating new technology in a structural fashion.

The second study concerns a technology development project with a focus on the interaction between the management and the technology developers. This case study is positioned in the category 'electro-optics' and the organization can be characterized as a Technology Intensive Organization active in the semiconductor industry. Both the organizations in the first and second case study are part of the same multinational. Finally, the main case study that is reported, involves the strategic development process prior to technology development. This case study is positioned in the category 'semiconductor processing' and the organization can be characterized as a Technology Intensive Organization active in the semi-conductor industry.

All these case studies have in common that they were executed in Technology Intensive Organizations. Two of the case studies were executed in a semiconductor organization while one was involved with the development of an optical element, while the other was related to the selection of a semiconductor device technology. The case studies include more or less all the phases prior to the product development. The results of these case studies will be confronted with a theoretical framework from which further hypothetical research questions will be defined.

Step 3: Crafting Instruments and Protocols

To acquire and structure data, instruments described by Miles and Huberman will be used. Structuring the data in this way will facilitate possible future research at other sites and will enhance generalization of the results and outcomes. The set up of a conceptual framework together with a structured qualitative data collection method will

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facilitate the step toward quantitative research, enabling broader testing of the findings. This is also advocated by Eisenhardt: if possible use both qualitative and quantitative data to obtain a synergistic view of the evidence. As previously mentioned I adhere to the stance that qualitative research is an important initial step to come to quantitative research. Although this last stage is not performed within this research project, it is considered to be very useful to anticipate these steps later on.

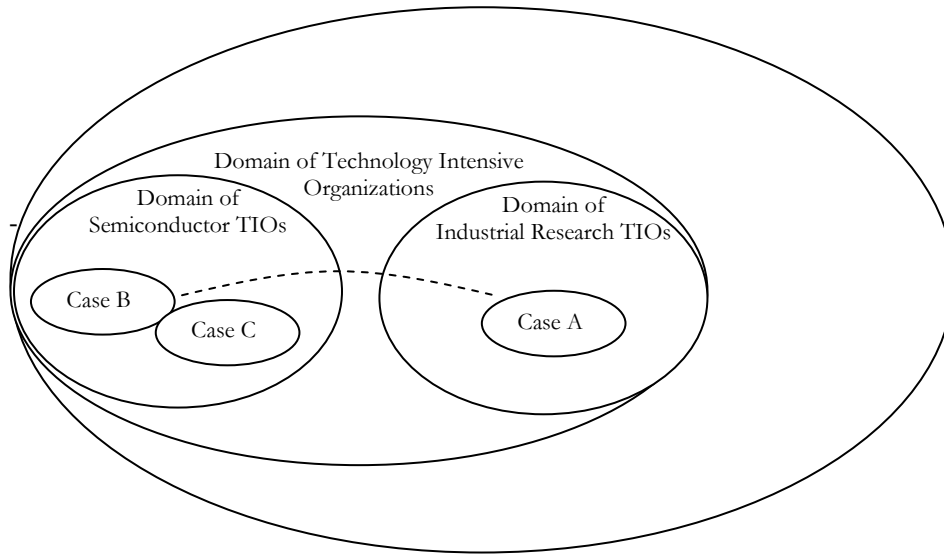


Figure 1.1: The organizational positioning of the case studies: All three studies were executed in a Technology Intensive Organization (TIO). Two were executed in a semiconductor TIO, while one was executed in the domain of Industrial Research TIOs. The organizations of Case A and B were part of the same multinational firm. Part of the organization of case study B evolved over years into the organization of Case C.

Step 4: Entering the field

The earlier mentioned methods of Miles and Huberman will be applied here as well as for data collection, structuring and analysis. As suggested by Eisenhardt the data collection and analysis will be applied with overlap in order to reveal necessary adjustments in the set up and application of the methods. The data collection methods that have been used for the initial case studies were based on the registration and reconstruction of historical cases. The main method utilized was the conducting of interviews with 'eye witnesses' and/or participants. The data collection of the main case study is based on written observations during technology strategy development workshops and sessions.

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Step 5: Analyzing Data

Basically, this project comprises multiple case studies at different levels in the organization. The idea is that the technological trajectories and the expected relationships to the technology development process are studied across departments within the organization and across organizations and in different application areas of the technologies. This plays an important role in the analysis of the data. For the data analysis displays have been used that are linked to the conceptual framework. A binning analysis of written field notes and interviews has been applied in order to reveal and recognize patterns. These patterns were manually laid out on a display, showing a particular structure of the process under study (see Appendix C).

Step 6: Shaping Hypothesis

In this step the constructs become more soundly affirmed, by connecting evidence from cross-angle and cross-level data analysis. This analysis should reveal a generic logic that spans the construct in all its relevant facets. From the two initial case studies, hypothetical constructs have been defined which served as important input for the setup of the third and main case study. The results of the third case study led to hypotheses that are ready to be tested in a more quantitative way and which are presented in Chapter 9.

Step 7: Enfolding literature

In this step the findings are compared both with conflicting literature and with confirming literature, in order to place it in perspective and to generalize the outcomes. In Chapter 2 a broad overview is given of the technology development process and the several viewing angles on the processes that take place within the development process. In the seventh chapter a reflective perspective is given based on related literature to a concept utilized in Chapters 5 and 6, which relates to the driving forces in technology development.

Step 8: Reaching Closure

In this last step the findings are reconsidered and, if necessary, the hypotheses are further sharpened. After this stage the constructs should be established and the research questions should, at a minimum, answer the questions within a given framework. In Chapter 9 the results of the study are presented as well as the contributions and the recommendations for further research.

1.7 Structure of the thesis

The Structure of the thesis is given in Figure 1.2. The thesis is subdivided in four main sections: The Theoretical Framework of the Study, Definition of the Field of the Study,

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Results of the Study, and finally the Conclusions, Discussions and Reflection of the Study.

I. Theoretical framework

In Chapter 2 a theoretical perspective of technology development and an overview of driving forces in the technology development process are presented.

II. Defining the field

In Chapter 3 a description is given of the technology development process. Although this can be seen as a result of this study, it is positioned here as an important element of the definition of the field.

In Chapter 4 a practical framework based on initial case studies is presented. In this section results are presented that have been found in earlier stages by analyzing two historical cases, position around technology development processes.

III. Results

In Chapter 5 the concept of Collective Frame of Reference (CFR) is presented that is thought to be explanatory for the course of actions during technology development processes.

In Chapter 6 the concept presented in Chapter 5 is studied by means of a case study. This study follows the strategy development related to a new technology and the course of actions during the initial development of this technology. Evidence is presented to establish the concept introduced in Chapter 5.

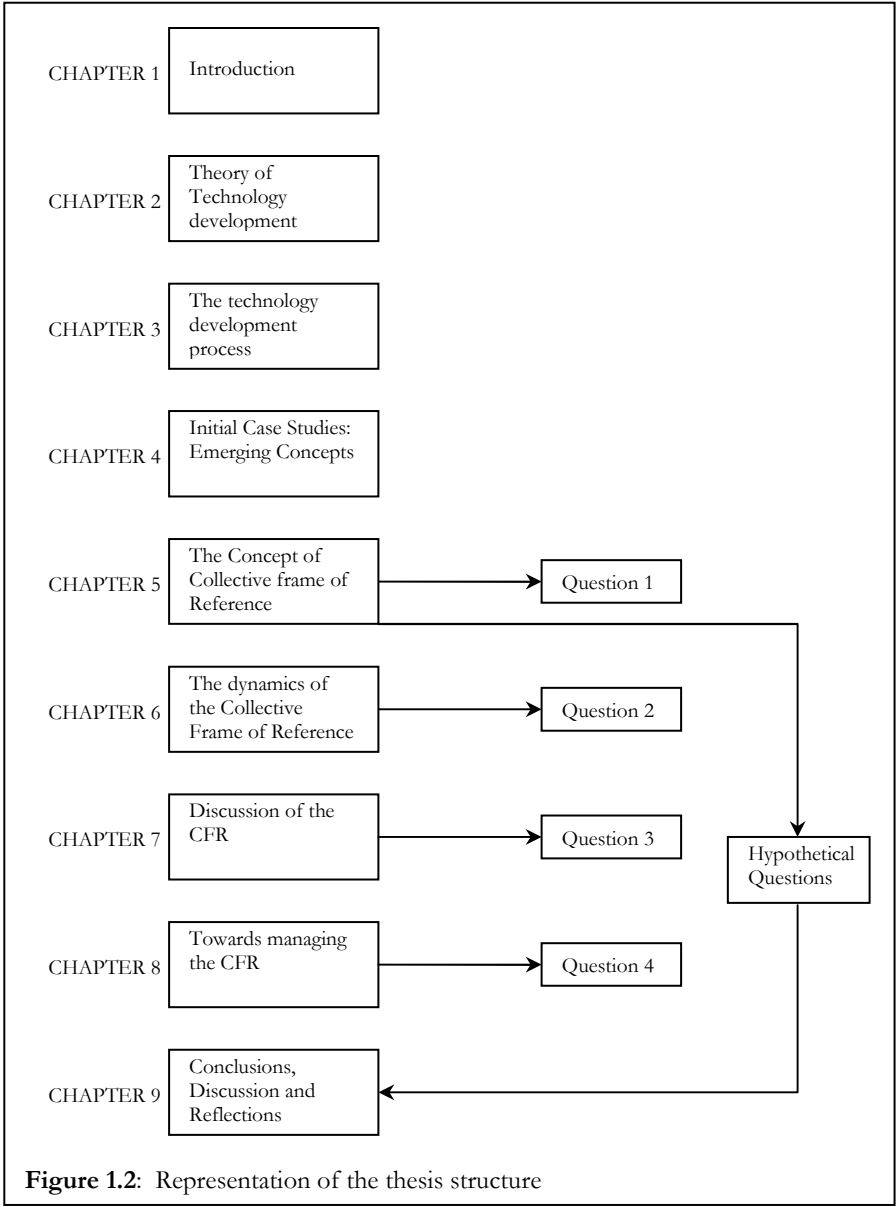
In Chapter 7 the implication of the findings in Chapter 6 is discussed and reflected in relevant literature.

In Chapter 8, the implications for the management of the technology development process are discussed, both at a management and the developers' level.

IV. Conclusions, Discussion and Reflection

In Chapter 9 the implication of the findings of this study is discussed and reflections on the work are given, as well as the contributions. Finally, the conclusions and recommendations for further research are given in this chapter.

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Chapter 2: Theoretical Framework

“The beauty of an invention differs accordingly from the beauty of a scientific discovery. Originality is appreciated in both, but in science originality lies in the power of seeing more deeply than others into the nature of things, while in technology it consists in the ingenuity of the artificer in turning known facts to a surprising advantage.”⁶

Chapter 2: Theoretical framework of Technology Development

Creating a theoretical framework around technology in general and (radical) technology development in particular is complicated. As discussed in Chapter 1, a unified definition of technology does not exist as it has several meanings and interpretations. Although technology development is considered as an important precursor for product development, it is and has been underexposed - especially in a relative sense given the massive number of publications and books written on product development.

One of the reasons is that the technology development process is not necessarily seen as a distinct organizational process, and often it is not organized as a dedicated process. It has been found that the term “innovation process” seems to capture both technology development and product development. Still, in line with a recent publication of Cooper, one of the main propositions of this research is that technology development is different from product development [Cooper 2006].

The working definitions as well as the research question given in Chapter 1 will serve as guidance for the theoretical framework of the study and its contexts. The framework and the elements given in the definitions should not only support the theoretical considerations given in this Chapter, but should also reflect the already present literature. This is not a simple task as there are many streams that are not necessarily directly related to, but certainly have relevant aspects or elements for, technology and its development.

The approach that has been chosen here is to look in two theoretical fields that are related to technology development. Positioning technology development as a precursor to New Product Development (NPD) assumes that the theoretical fields should be related to a certain extent and may allow for drawing parallels with the theoretical framework of the New Product Development process. On the other side of the spectrum, Scientific Discovery may be considered as the front-end for the technology development process and, based on the same reasoning as with the relationship between technology development and new product development, it can be expected that the theoretical fields are connected.

A line of reasoning to support such an approach is the relationships between the fields itself. Figure 2.1 gives a representation of the relationships. This relationship is considered valid for ‘modern’ technology development and excludes the empirically

⁶ Polanyi in “Science and Technology”, *Personal Knowledge: Towards a Post-Critical Philosophy*, Harper Torch books, NYC, 1962, 174-184

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obtained technology. For example, the aeroplane was created without a specific scientific discovery although one could speak about a technological discovery.

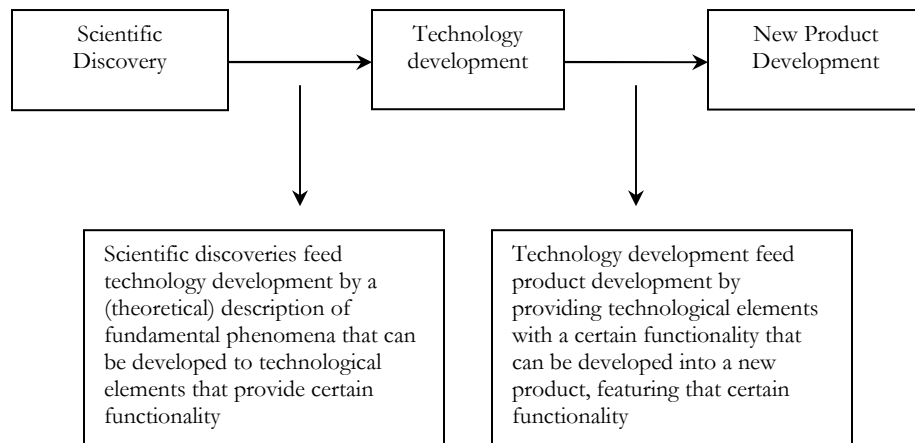


Figure 2.1: A description of the relationship between Scientific Discovery, Technology Development and New Product Development

However, in modern times as science and technology are progressing, the scientific discovery and technology development are much more coupled. Mowery and Rosenberg state that science is becoming less a matter of independent unfolding knowledge generation and more a matter of responding to technological progress: they actually suggest that “technology determines the agenda of science”[Mowery & Rosenberg 1998, p.173-175]. The latter statement suggests a direct feedback from technology to scientific discovery and this is not considered in this study.

The question is whether it is justified to assume that the theoretical fields are connected in such a way that a theoretical perspective can be created based on an interpolation between the theoretical fields of scientific discovery and new product development. Providing a ‘scientific’ answer to this may require a dedicated study which lies outside the scope of this research. However, it can be deduced that on the basis of similarity of the processes within these fields, that it may indeed be justified to create a theoretical framework of technology development by interpolation between the scientific discovery theories by e.g. Popper, Polanyi and Kuhn and the theoretical framework that has been formed around new product development (e.g. Brown and Eisenhardt). A theoretical indication can be found along the lines of human problem solving as studied by Simon et al. [Simon 1965] stating that the human problem solving cycles are basically the same in the scientific discovery process and other processes. Both technology development and new product development consist of problem solving

Chapter 2: Theoretical Framework

cycles, which may already justify an interpolation between the theoretical fields concerning the theory of (human) problem solving.

A more pragmatic approach to the question above is that others did apply this interpolation already or, perhaps more precise, utilized an extrapolation from the scientific discovery framework. Examples are found in economic literature where Nelson and Winter based their evolutionary economic theory on Kuhn's theory of scientific discovery [Kuhn 1970] which Dosi used later to explain the role and importance of technology in economic development [Dosi 1988]. This theory was later connected to new product development by Brown and Eisenhardt [Brown & Eisenhardt 1995]. Whether these extrapolations were properly grounded is somewhat uncertain but this will be discussed later in this Chapter.

On the basis of the of human problem solving case found by Simon and the parallels that have been drawn by Nelson & Winter, Dosi and Brown & Eisenhardt, it is assumed that the theoretical framework can be based to a great extent on both the theoretical fields of Scientific Discovery and New Product Development as shown in Figure 2.2.

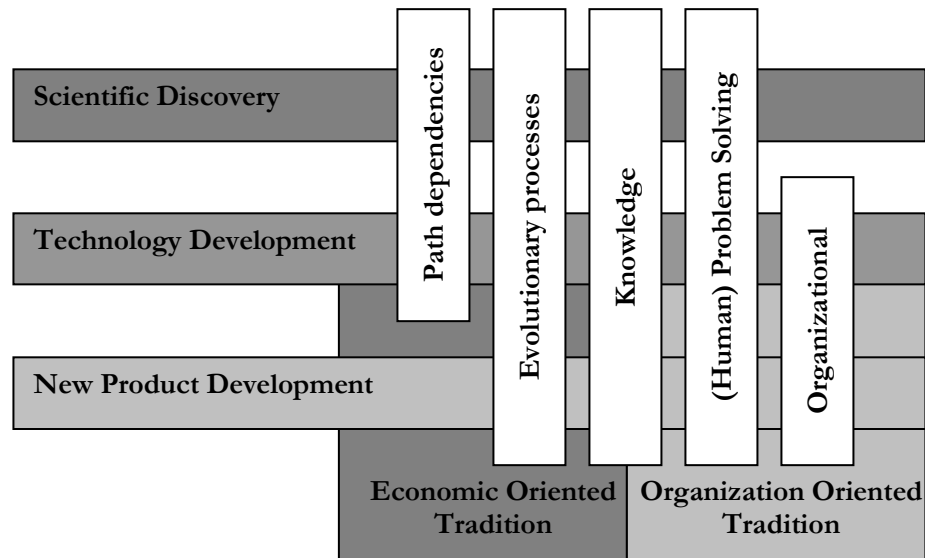


Figure 2.2: An overview of the connecting elements of the theoretical framework of Scientific Discovery, Technology Development and New Product Developments.

In Figure 2.2 some connecting elements are shown which have already been found to be relevant for the theoretical framework of technology development. The elements are derived from the often-cited review paper from Brown and Eisenhardt (1995) and based on the fundamental work from Popper, Polanyi, Kuhn and Simon. The

connecting elements are (roughly) subdivided in an economic oriented tradition and an organization-oriented tradition.

For example, knowledge is a central concept that not only covers the middle ground between the two traditions, but also covers the three disciplines. Based on this simple structure, a further theoretical orientation will be done and described in this Chapter. First the theoretical fields of scientific discovery and new product development will be described and then the connecting elements between these fields will be described. The Chapter will be concluded with the description of the theoretical framework of technology development.

2.1 The field of scientific discovery

The process of scientific progress and scientific discovery has been explored by great philosophers like Popper, Polanyi, and Kuhn in the 20th century. All contributed to a fundamental theoretical explanation about science and scientific discovery. The focus of these philosophers is somewhat different though. Where Popper and Kuhn ‘battled’ a fundamental discussion about scientific discovery, which was related to ‘how it should be’ and ‘how it is’, Polanyi addressed issues about the freedom of science and the role of personal knowledge in scientific discoveries.

In his “the republic of science”, Polanyi argues that science should be conducted with a free spirit, free of censure, imposed by political and religious institutes. Polanyi’s contribution is important in several ways. First of all it made a political statement about the delicate subject of external influences on scientific processes, which was specifically fuelled by the Soviet influence on scientists in his times. Secondly, Polanyi addressed

Dialogue box 2.1: Scientific Progress, Mathematical Truth and Observations

The history of thinking on science and scientific progress is about as old as science itself. The first known scientific debate among the ancient scientists, who would call themselves natural philosophers, was about the origin of materials. The materialist philosophers like Thales of Miletus (624-546 BC), Anaximander (610-546 BC) Anaximenes (585-525 BC) Heraclitus of Ephesus (about 535 - 475 BC), and finally Empedocles of Acragas (490-430 BC) debated about the origin of materials. Proposed theories were criticized and replaced by other ones. These material philosophers all assumed material as a continuum and proposed first Water (Thales) and later Water, Fire, Earth and Air (Empidocles) as basic building blocks for all materials. Not much later Democritus of Abdera (lived about 410 BC) introduced the concept of atoms. The first known debate about science was between Plato and Aristotles. Plato argued that reality is imperfect and that only ‘mathematical truth’ could provide scientific answers, while his student, Aristotles argued that observation of the reality will provide the scientific answers. (Source: Stanford Encyclopedia of Philosophy (SEP))

Chapter 2: Theoretical Framework

the question which is very relevant for this thesis: Why are scientists or groups of scientists making progress in a certain direction without a direct and explicit guidance? His answer related to the concept of tacit knowledge as an explanatory element - which was important enough to induce a massive body of literature on knowledge, its creation and its management.

Although Simon is not considered to be a philosopher 'per-se', he had a distinct view on scientific discovery and contributed largely to the understanding of human problem solving and decision making. Simon spent a lot of his professional life on decision making and interestingly enough he did not limit himself to scientific problem solving. Actually his doctoral thesis was about administrative behaviour in the context of decision making. His passion for Artificial Intelligence fuelled his interest for the Human Problem Solving process and the modelling of that process. Much later he focussed on Scientific Discovery together with Klahr [Klahr & Simon 1999].

The literature on Scientific Discovery is interesting as it tries to obtain insight and understanding of possibly one of most unpredictable processes known to humanity. As predicted specific scientific discoveries are rare or may be even non-existent, it must have intrigued and inspired great thinkers to grasp the structure of the unstructured. If ever discoveries were predicted, it is mainly based on progressive theoretical considerations which translate into verification problems that need to be solved.

In this problem solving process the answer, in the form of a discovery, comes after the development of a theory. Examples are the relativity theory of Einstein; many of his predictions have inspired numerous others to solve the problems that have been created by his predictions and which took many years to resolve in a scientific discovery. Popper argues however, that a theory is never proven right and that a solution to an induced problem is never a guarantee that the underlying theory is true. This reasoning will also shed a specific light on the 'truth' as it, according to Popper, but a definition never will be found.

With the risk of ignoring many great thinkers in the near and far past, it makes sense to consider Popper, Polanyi, Kuhn and Simon as the four major contributors of the modern view on scientific progress and scientific discovery. Although these four worked fairly independently, their work opened up several streams of literature like scientific knowledge and problem solving (Popper), human problem solving and decision making (Simon), (tacit) knowledge (Polanyi), evolutionary economics and punctuated equilibrium (Kuhn). An interesting observation is that much of the work of these philosophers forms a foundation of the current management literature. Having said that, it makes sense to have a closer look at this work and elaborate on the implications for technology and its development

2.1.1 Problem solving and decision making

Popper believed that science, like virtually every other human activity, consists largely of problem-solving cycles and that science is not created by unguided observations. He

poses that 'pure' observations do not exist; they are always selective and loaded with theory. Consequently scientists do not just experiment; they do experiments for some reason - whether it is because of personal beliefs and passions or because of an idea for a theory.

This is very similar to the notion of Polanyi that 'acts of discovery' are charged with strong personal feelings and commitments or as he calls it: 'passions'. Polanyi derives 'tacit knowledge' from this as a guiding principle or motivation to conduct experiments. Consequently, Polanyi does reject, like Popper, the position that science is value-free, and relates exploratory acts to informed guesses, hunches and imaginings. Whatever the motivation, whether it is related to personal beliefs or other ideas, Popper assumes that it is always related to problem solving.

Simon studied the problem solving aspects of scientific discovery and made attempts to model this aspect. Later, Klahr and Simon came to the conclusion that the problems which need to be solved during the scientific discovery process are not different from other, more daily problems [Klahr & Simon 1999]. They identified that the difference between problems in science and other fields is mainly the difference in the level of knowledge. Modern scientists need years of training and learning to get to a level where they can produce new knowledge as front runners in a specific field.

This is in agreement with the important thought of Popper that human knowledge can be grown by problem solving and, by definition, requires 'a leap in imagination' as new problems are outside what is known from previously solved problems. Gathering knowledge alone is not enough for a scientist to lead the way to new knowledge; once at the front line, the scientist needs to have the ability to think 'outside' the known patterns.

Kuhn, inspired by Polanyi's republic of science, adds an extra dimension to the problem solving by making a distinction between 'normal' science and 'revolutionary' science. Kuhn argues that history shows that science is progressing in a phase of gradual change, punctuated by a revolutionary phase. In terms of problem solving Kuhn calls normal science 'puzzle solving' and suggests that no dramatic outcomes are expected. The scientist does not have the answer in the beginning, but based on similarity of previous problems or puzzles, he is confident that a solution is available and the path towards this solution is identified. For revolutionary science the scientist basically does not know which puzzle to solve. According to Kuhn this results in a 'crisis' and requires a different kind of problem solving mode. Kuhn argues that this crisis allows for unconventional methods in order to obtain unconventional solutions. This is one of the controversial issues that have been rejected by Popper, who assumes that the problem solving is always related to previously found solutions. Popper however makes a distinction between risky and less risky theories. So where Kuhn would identify Einstein's work as revolutionary science where a new puzzle has been created, Popper would identify Einstein's work as the creation of a theory as every other theory only a more risky one, which will be accepted till it is falsified.

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The Problem Solving process has been studied and described in detail by Simon and others. Simon's fascination for the ability of the computer to solve problems did motivate him to look in more detail to the problem-solving process. Klahr and Simon assume that a problem consists of an initial state, a goal state and a problem space that contains both states. The problem space is defined by a set of states, operators and constraints. Provided that there is a 'valid' path between the initial state and the goal state, a search of the solutions space will result in a solution where the goal state has been reached.

The search process can be described with a wide range of activities. Typically, the problem solving starts with a selective search through the full spectrum of possibilities. In general the solution space is virtually infinite and random search will result in large inefficiencies. Klahr and Simon identify Strong and Weak Methods to search the solution space [Klahr & Simon 1999]. A strong method is an analytical method that allows solving the problem with a known analytical description and basically allows for obtaining the solution without searching. The weak methods are used if little is known about the problem and no analytical method is available or known⁷. Klahr and Simon distinguish several weak methods that can be utilized to guide the search for solutions:

- Generate and Test (or trial and error): This method is based on variation of one or more parameters within a set of solutions and boundary conditions. The complexity of the search becomes higher if the target state can only be reached by varying several parameters.
- Hill climbing: In this method a logical metric for milestones is assumed that will bring the solution closer to a known end-goal. The end goal is specified in such a way that a convergent approximation is meaningful.
- Means-to-end: This is basically a differential analysis between a current data point and the goal. Again it is assumed that a convergent path exists towards a specified goal and that the problem solver can define coherent actions to let the difference approach zero.
- Planning: For this method a procedure is utilized whereby a simplified model is constructed of the 'real' problem space and then the problem is defined in the simplified problem space. After the solution is found with the one of the five weak methods, it will serve as a plan for the solution of the real problem.
- Analogy: This involves recognition of similarities of the problem to other solved problems. Consequently the problem can be transferred to a different problem space where more methods and/or experience are available.

⁷ This is subjective. If an analytical method is available but is unknown to the problem solver, the search of solutions will rely on weak methods. Although the result can be the same: both methods may lead to a solution; the efficiency is very different.

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For both strong and weak search methods, the problem solver needs a motivation to move in a certain direction along the search path. It is assumed that the problem solver will rely on information that is stored in her or his memory and that this information is addressed by certain triggers of clues. Simon et al. particularly studied the number of patterns that an 'expert' needs to recognize to take up the complex problem solving tasks. These patterns allow the expert to access the proper information to define actions that will lead to a solution. The number of patterns an expert explores is high, in the order of ten thousands; it is however relatively small compared to the total number of possible solutions.

According to the contemporary theory of problem solving, experts have the behavioral ability to apply phenomena like intuition and judgment to the search process that makes it possible to find solutions for difficult problems and in a short time span. Apparently the intuition and judgment allows for rapid access to the expert's knowledge. It is not assumed that an expert can always rely on this mechanism as certain problems may lie outside the known patterns. In these situations, experts need to learn and conduct a painstaking process of developing one or more hypothesis and verify whether these are true or false.

This process is described by Popper in more detail. The 'procedure' that is followed by the problem solver is based on tentative hypotheses that are tested by deduction and compared to other hypotheses. The conclusions drawn from this process are not necessarily compared with "facts" as it is a highly subjective deliberation. Consequently the subjective factors like interests, expectations, and wishes are factored into this process and will influence the outcome of the process. Popper also stresses that independent creative imagination plays an important role to solve problems as they require solutions outside the known solutions. In more detail Popper specifies the deductive procedure in the following steps:

- (a) Step 1: formal - by testing the internal consistency of the theoretical system in order to see if it involves any contradictions.
- (b) Step 2: semi-formal - by distinguishing between empirical and logical elements the scientist makes the logical form of the theory explicit. This helps to define the proper research questions and gathering the proper empirical data. Likewise, analytic and synthetic elements are distinguished.
- (c) Step 3: comparison - the comparing of the new theory with existing theories. Based on advancement or lack of advancement in terms of 'theoretical progress', a theory will or can be rejected or accepted. Initially, this is an internal process; before a scientist brings out a new theory, a subjective internal judgment of the theoretical progress will be made. If internally rejected, the theory will never be known to a broader public. However if accepted, the theory will be evaluated by others and a broader accepted theoretical progress will make the theory sustainable. Theories do not necessarily replace each other, and several theories can coexist. This situation can exist for a longer time especially if empirical data is not or sparsely available. However it is in the end

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expected that the theory that has more explanatory value will prevail, or a unification of several theories will merge into a unified theory.

(d) Step 4: testing - in this last step the testing of a theory by the empirical application of the conclusions derived from it. If these conclusions create a 'reality', the theory is accepted, although not necessarily true. In case of discrepancies, the theory cannot be fully correct and scientists will be motivated to find a better theory.

According to Popper's philosophy of science, theories can only be proven false but not proven true. Consequently all knowledge is provisional, conjectural, and hypothetical. Although this may lift the burden of the need of proving theories to be true, it requires a critical mind to prove that a theory is false and the imposed burden of science is that every theory, sometimes (provisional) accepted for a long time, should be critically evaluated and tested.

2.1.2 Decision making

Herbert Simon connects problem solving to decision making, and basically assumes problem solving is an integral part of the decision making process. Simon considered the following steps within the decision making cycle [Simon 1986]:

- 1: choosing issues that require attention
- 2: setting goals
- 3: finding or designing suitable courses of action
- 4: evaluating and choosing among alternative actions.

The first three steps are part of the problem solving process, while the last step is the actual decision making. Although Simon clearly had an interest in decision making in firms, he considered the theoretical background of decision making as universal and valid for scientific decision making as well. This is in line with the general assumption that the problem solving process is universal for human activities. As discussed in the previous section, scientific discovery is considered to originate from problem solving cycles (see Figure 2.3). An important part of decision making requires the ability to change 'opinion' during the process. Simon points at the Bayesian statistics to deal with new information [Simon 1965]. Although opposed by scientists because of its subjectivity, Bayesian statistics work very well in situations where decisions have to be made. As decision making is a subjective activity, a 'Bayes' rule is very helpful as it combines existing knowledge with new information (see dialogue box 2.2).

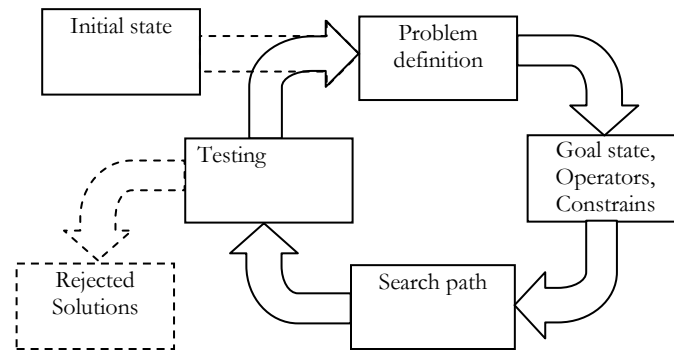


Figure 2.3: The problem solving cycle

Although not explicitly used in this particular context, it makes sense to consider the decision making process that guides scientists during the act of gaining knowledge and discovery. Interestingly, the problem solving process itself is based on certain decisions and choices. It starts with the choice of an initial problem. The choice of the initial problem can be exogenously or endogenously motivated. The scientist can follow his intuition, passion and/or reasoning and deduct a certain problem description from these.

An endogenously -motivated problem does not necessarily make it to an explicit description; it can be confined to the mind of the scientist. The scientist can choose to work on a problem that has been identified by a scientific community as a generic problem. It is expected that the choice of problem is part of a larger scheme of issues and problems that need to be solved. This is generally more explicit; the problem is often described in published papers and sometimes descriptions of earlier attempts by

Dialog box 2.2 Bayesian Statistics

"The essence of the Bayesian approach is to provide a mathematical rule explaining how you should change your existing beliefs in the light of new evidence. In other words, it allows scientists to combine new data with their existing knowledge or expertise. The canonical example is to imagine that a preconscious newborn observes his first sunset, and wonders whether the sun will rise again or not. He assigns equal prior probabilities to both possible outcomes, and represents this by placing one white and one black marble into a bag. The following day, when the sun rises, the child places another white marble in the bag. The probability that a marble plucked randomly from the bag will be white (ie, the child's degree of belief in future sunrises) has thus gone from a half to two-thirds. After sunrise the next day, the child adds another white marble, and the probability (and thus the degree of belief) goes from two-thirds to three-quarters. And so on. Gradually, the initial belief that the sun is just as likely as not to rise each morning is modified to become a near-certainty that the sun will always rise." Source: Economist 2000.

other scientists are available. Independent of the origin of the initial problem, the scientist has to make smart choices during the problem solving cycles to make a certain progress. One could argue that most of these choices may be based on an intuition, which separates the successful scientists from the less forthcoming scientists, but still it requires a decision to search in a certain direction. Once the initial problem has been chosen, certain goals are set in terms of expected outcomes of the problem solving cycle. Again this requires a decision with respect to the goal selection; the scientist makes a choice about which goals should be set. Some scientist may choose for a stepwise approach, where the goals are set in a stepwise manner, others may just focus on the end goal. In the next step of the problem solving cycle, the scientist decides on the search paths that he wants to explore. This search path is in general based on certain reasoning. The reasoning is a hypothetical assumption that a certain state can be achieved by manipulation of certain parameters. Once the problem solving cycle is successful, this reasoning will form the basis for a new theory or theoretical relationship. The last step in the cycle is the evaluation and validation step. The underlying decision here is the selection of the evaluation or verification methodology. Once chosen, the results will form the basis for the problem selection and definition in the next cycle. The critical decision making around the problem solving cycle core is given in Figure 2.4.

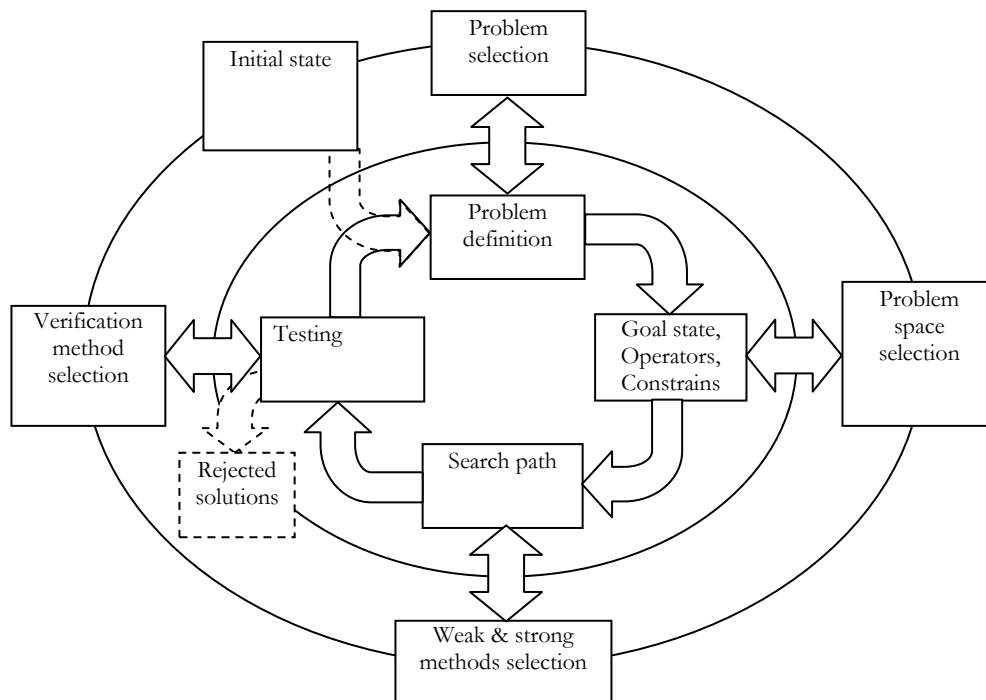


Figure 2.4: An interpretation of the decision making around the problem solving cycles based on the work Simon [Simon 1987, Klahr & Simon 1999]

2.1.3 Scientific Knowledge

Popper is quite clear about scientific knowledge; it is generated by problem solving cycles and it is provisional, conjectural and hypothetical. The latter three characteristics are derived from the fact that according to Popper, scientific theories are never true, and that scientist 'avant la lettre' always should try to 'overthrow' an existing theory. This requires some explanation related to the definition of knowledge that was adopted in Chapter 1, p.16. From a Popperian point of view this definition is complicated as 'True' is basically meaningless, but one can say that 'Justified' may add a subjective notion to the definition that indicate that knowledge is not true in an absolute sense.

Both Polanyi and Kuhn have the notion that indeed subjective belief is responsible for holding theories as true. Polanyi considers this from an individual level, arguing that many theories became mature by a persistent belief of the scientist. The scientist can be convinced that a new or current theory holds, even when contradictory evidence is observed. Kuhn's uses a similar concept for explaining a scientific paradigm. According to Kuhn, a paradigm is valid for as long there is a consensus on the validity or truth of a theory. Both Polanyi and Kuhn reject the positive scientific, Popperian view that a theory should be rejected as negative evidence is observed. In the context of scientific knowledge, Popper grants scientific knowledge certain truthfulness, till it can be falsified.

Kuhn argues that the knowledge will be truthful until an accumulation of anomalies results in a crisis and Polanyi considers the individual belief as a mechanism to cope with contradiction to the current knowledge. Furthermore, Polanyi makes scientific knowledge relevant by stating that scientific knowledge is "the knowledge of an approaching discovery". And holding such knowledge implies "an act deeply committed to the conviction that there is something to be discovered" [Polanyi 1967]. Herewith Polanyi considers scientific knowledge meaning full as it leads to discoveries. In general Polanyi personalizes knowledge, where the holder uses its judgment to link the evidence to the external reality.

2.1.4. Paradigm Concept

Kuhn studied many historical scientific discoveries and found that the major discoveries had a revolutionary character and were related to a 'crisis', which can be described by a discrepancy between the 'known' and the 'experimental and theoretical facts'. Consequently, a new knowledge base has to be created to support the reality. Outside this period of crisis, science moves along with a gradually increasing knowledge and understanding.

The evolutionary scientific progress takes place within a certain paradigm, which will hold until the experimental and theoretical reality can no longer be explained by the ruling paradigm. Consequently a paradigm shift is required to allow further progress outside the previous paradigm. Kuhn argues that this paradigm shift comes with a crisis as soon as an uncertainty falls over the scientific community and basically the direction

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is unknown. This period of reorientation, is much more intensive than evolutionary periods and requires unconventional approaches and solutions that are disconnected from the existing knowledge base.

Popper does not distinguish the evolutionary and revolutionary phases of the scientific discovery. Popper opposed historical analysis and was very skeptical of the use of historical analysis to predict future developments. One of the reasons he disagreed with Kuhn's theory was due to the fact that it was based on historical analysis - although Kuhn used this to explain the process rather than making predictions. Popper's view on scientific discovery is based on a scientific community that tries to refute the existing theories on a constant basis. He distinguishes risky and gradual opposing theories which may be linked to revolutionary scientific progress as being characterized by posing a 'risky' theory and evolutionary scientific progress by posing a gradual theory. In a sense Popper's view on scientific progress is negatively motivated as it relies on a mechanism that new theories are posed and that the scientific community spends the effort to prove a theory wrong, and never right. Kuhn's philosophy is different. He assumes the revolutionary scientific development as a higher order of development and by definition attaches a positive qualification to a revolutionary development as a solution to a "crisis".

Moreover Kuhn rejects the Popperian negative motivation and argues that in case of an evolutionary scientific development; the scientists are collectively committed to an underlying theory and use this to gain scientific progress and not so much try to overthrow the underlying theory. This commitment is brought into connection to shared theoretical beliefs, values and methodology, which Kuhn identifies as a paradigm. Basically, Kuhn states that following a paradigm works very well for 'normal', evolutionary scientific development, and rather than Popper's falsification theory, Kuhn's view is that anomalies are ignored and/or waived. As long as the series of disturbing anomalies do not result in a 'crisis' the community will follow the paradigm. Consequently, a crisis basically means that the paradigm cannot be followed with confidence anymore and a search for a new paradigm is initiated.

Polanyi addresses a related question about motivation which is very relevant for this thesis: Why are scientists or groups of scientists moving their work in a certain direction without direct and explicit guidance? This question that Polanyi asked himself and others is very inspirational to this work. In a Popperian approach this answer will be falsification of existing theories. More in line with Kuhn, Polanyi answers the question with the concept of tacit knowledge as an explanatory element. This concept of tacit knowledge was important enough to induce a massive body of literature on knowledge, its creation and its management.

2.2 The field of new product development and innovation.

At the other end of the spectrum, diametric to scientific discovery, the product development field is much more scattered and concepts are borrowed from many different fields. The number of viewing angles to product development is overwhelming, which makes it impossible to give a complete overview. To describe the relationship to technology development in all aspects is equally impossible. One of the overlapping areas that can be found during a scan of new product development is the field of innovation in organizations. Many contributions in literature acknowledge the role of technology in the innovation process, especially for Technology Intensive Organizations.

An important contribution from Jelinek & Schoonhoven describes the innovation process for TIOs which is specifically active in electronics [Jelinek & Schoonhoven 1990]. They recognize that technology decisions are important and are of 'you bet your company' magnitude. Several other contributions discuss a wide spectrum of issues in innovations and give comprehensive overviews of the important issues in (technological) innovation [Tushman & Moore 1982, Rosenberg 1992, Burgelman 2001, Schilling 2008].

Further to this, many contributions discuss the conditions which should be shaped in order to obtain effective technological innovations, for example in organizational learning [Jelinek 1979, Argote 1999], the organization forms [Pettigrew & Fenton 2000], and government policies [Branscomb & Keller 1998].

Interestingly enough, innovation is often related to evolution in technologies, but without discussing the particular development of technology and how firms can drive these technological developments. This is one of the particular areas where this study intends to contribute.

A paper published by Brown and Eisenhardt in 1995 has been, and still is, cited in many articles on product development. It gives an overview and status quo of the product development literature. In the paper, two main streams of literature are mentioned: the economic oriented tradition and the organization oriented tradition [Brown & Eisenhardt 1995]. In analogy with the product development literature, this distinction seems to be very relevant for technology and its development as well.

Actually, in the economic oriented literature, the link between product development and technology was basically laid by Schumpeter and Nelson and Winter. Schumpeter related the relative success of individuals with a new technological idea on the one hand and large companies that were caught by surprise if a new technology emerged [Schumpeter 1932]. Nelson and Winter related the development of technology to the previously discussed theory of Kuhn, discussed in the previous sections [Nelson & Winter 1982]. Kuhn's theory explains the path dependency in science and the paradigm shifts that occur in conjunction with revolutionary scientific discoveries. Moreover Nelson and Winter are the main exponents in establishing the evolutionary economic

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theory which is to date very popular. Linking these and other publications may not only relate technology to product development and innovation, but also link technology development to evolutionary processes and moreover relate the development of technology to science and scientific discovery.

The organization oriented tradition is less explicit about the role of technology and its development and is much broader. However, the overview paper by Brown and Eisenhardt, presents a model for the product development process and it might be useful to elaborate on its relevance for technology development. Following the distinction of Brown and Eisenhardt, the economic tradition and the organizational tradition will be discussed. These two streams will be described and the relevance for technology development will be discussed.

2.2.1 The Economic tradition

The economic tradition in general relates new product development and innovation to evolutionary economical development. In this tradition, interestingly the role of technology is identified as very important for the innovation power of companies. One could say that this is even more pronounced than within the non-economic product development literature itself. However, within the economic tradition, the technology is discussed as an available resource without giving much attention to the technology development process. That being said, the micro-dynamics also seem to matter more in the economic tradition [e.g. Antonelli 1999].

Some historical analyses which reveal patterns like path dependencies and evolution of technological development sparsely identify technology development as a specific process which should be addressed specifically to obtain a competitive edge with respect to innovation.

The economic tradition for new product development and innovation traces at least back to the 1930's when Schumpeter made an important distinction between 'circular flow' and 'economic development' [Schumpeter 1932]. He was intrigued by single entrepreneurs who brought innovative products to the market, often based on new technology, and who were able to catch large companies by surprise and change the competitive landscape instantly. To Schumpeter, this could be only the result of two different modes; one of exploiting existing 'combinations', like what large production companies mainly seem to do, and one of creating new 'combinations', like what entrepreneurs seem to do. Schumpeter was especially intrigued by the creative destruction at a microscopic economical system, but his work clearly contained evolutionary elements, which were related to new technologies that led to new combinations and which made old combinations unfit to survive in the economical system.

Much later Nelson and Winter, unhappy with economic theories at hand, developed an economic theory that expanded this concept in several directions [Nelson & Winter 1981]. Primarily Nelson and Winter considered the mode of operation on an individual,

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a firm and an industry level and did not necessarily separate the mode between two entities: the entrepreneur and the large companies dominating in the economic system like what Schumpeter assumed. In this perspective they considered an individual with certain skills and then worked their way up to a more macroscopic view on economic development from an organization afflicted with routines and an industry afflicted with economical variation and selection.

Nelson & Winter also make a distinction between two regimes; one of full routine, with incremental change, and one with radical change indicated by major innovation. This distinction is less strong than considered by Schumpeter, who looked at the entrepreneur as a major change agent, opposed to the large firm, uninterested in any change and just exploiting the currently available production factors. Nelson & Winter fill in the gaps between those extremes. On the one hand they recognize that firms do develop themselves in an incremental way, within their organizational structure and routines, while on the other hand the firm can enter into a 'major innovation' regime, again within the existing organizational structure, but with new routines to support the change. The change is always followed by a development towards equilibrium. This equilibrium, allows the firm to 'harvest' its economical potential created after a change. Consequently, Nelson & Winter consider a firm as sustaining economical entity that is capable of changing itself in a moderate and continuous fashion and which is striving towards equilibrium to realize the gained economical potential.

Interestingly, Nelson & Winter were inspired by the earlier discussed theory of Kuhn, and applied many of elements of his theory to their novel evolutionary economic theory. An exponent of this is technological regimes.

As part of their evolutionary theory, Nelson and Winter defined a "technological regime" as the nature of technology and its development in the spirit of the knowledge based theory of production (see also Rosenberg 1976). In this perspective the development of technology is seen as a problem solving activity, which is embedded in routines that represent an existing knowledge base within the organization.

And later Winter introduced a technological regime as a particular knowledge environment where problem solving activities take place - as a kind of restricted domain - confining the 'solution space' of the problem solving cycles [Winter 1984]. Winter also made a distinction along the earlier discussed entrepreneur vs. established firm, by defining an entrepreneurial regime and a routinized regime. The entrepreneurial regime is characterized by turbulent and scattered development activities, while a "routinized" regime displays a structural and systematical development.

Malerba and Orsenigo found evidence that these two regimes divided the industrial activities roughly in two groups: the entrepreneurial regime prevails in organizations dealing with non-electrical machinery, instruments and traditional technologies, while the routinized regime prevails in organizations dealing with chemical and electronic technologies [Malerba & Orsenigo 1996].

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Marsili distinguish five groups of organizations in this perspective; science based (e.g. dealing with electronics, pharmacy), Fundamental process (e.g., dealing with chemicals, oil), Complex systems (e.g., dealing with aircrafts, vehicles), product engineering (e.g., machinery, instruments), and Continuous process (e.g., dealing with food, material

Learning	Three typologies of learning: <ul style="list-style-type: none"> - technical opportunity conditions; the range of technical solutions that can be achieved with the firms problem-solving activities - “appropriability” conditions; the ease of protecting innovations from competitors. - the degree of cumulativeness of innovation; the extent of technical solutions that can be build on past achieved solutions
Technology entry barriers	The ease with which an external firm can access a pool of technical opportunities. This is related to appropriability in that firms which can protect their innovations well increase the entry barriers for external firms.
Technology Diversity	Represents the number of technology trajectories along which the firm can progress by technological learning. The degree of technological diversity defines the strength of the technological regime.
Technological Diversification	Depends on two factors; the possibility for firms to exploit emerging technological opportunities and the need to coordinate different technologies due to the complexity of the product.
Sources of knowledge	A firm has to integrate several sources of knowledge to be successful. These sources can originate from competitors, suppliers, customers and institutes and universities.
Nature of knowledge	Knowledge has four distinct characteristics: <ul style="list-style-type: none"> - Tacitness; un-codified knowledge, difficult to communicate. - Observability; the amount of knowledge that is revealed during use. - Complexity; the amount of information that is required to characterize the knowledge. - Systematic; to what extent the knowledge is independent.

Table 2.1: Overview of the characteristics of technology regimes according to Marsili [Marsili 1999]

processes) [Marsili 1999] Furthermore, Marsili defined several characteristics that define the technological regime, summarized in Table 2.1. The elements given in Table 2.1 are characterizing the technological regime a firm operates in.

These characteristics together determine, in an evolutionary or dynamic economical perspective, the environment a firm is situated in and which barriers it will encounter to develop the technologies along the paradigms related to the technological regime. A technological regime is a macroscopic perspective that provides a macroscopic view on technology development within the context of an economical system. Based on the organizational distinctions and technological regime characteristics Marsili came to a

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typology of technological regimes. These regimes and their characteristics are summarized in table 2.2.

Science based regime	This regime has high technological opportunity level, high entry barriers in knowledge, high persistence of innovation external knowledge sources are public institutes and joint ventures, mainly product innovation
Fundamental process regime	Similar to Science based regime, but with lower level of technical opportunity, less scientific knowledge input and mainly process innovations
Complex knowledge system regime	Has medium-high levels of opportunity, entry barriers in knowledge and scale, Medium persistence of innovation, High degree of differentiation in technical competencies
Product engineering regime	High level of opportunity, low entry barriers, medium persistence of innovation. External knowledge from mainly users
Continuous process regime	Low level of opportunity, low entry barriers, low persistence of innovation

Table 2.2: Overview of technological regimes according to Marsili 1999.

Based on Nelson & Winters evolutionary economic theory and Kuhn's scientific discovery theory, Dosi introduced the concept of 'technological paradigms' [Dosi 1982]. Analogue to a scientific paradigm, technologies seem to be afflicted with a path dependency that results in a channeling of the research efforts into a more or less predefined manner. Dosi defined a technological paradigm as "a pattern of solution to selected technological problems based on selected principles derived from natural sciences and selected material technologies". Dosi also uses this concept to explain the sector wide developments in, for example, the IC industry, following the so-called "Moore's Law" [Dosi 1982]. Rosenberg et al. refers to the path dependent nature of growth with a similar although more geographical oriented notion (e.g. why is Germany's chemical industry consistently leading in the world) [Rosenberg 1992, p.96]. Egidi notes as well that technological innovation is the result of problem solving activities and that this is very similar to the process of discovery [Egidi 1997]

The notion of paradigms implies that the technology development takes place in incremental steps and basically builds on what was developed before. It also assumes that an organization builds up a certain (tacit) knowledge and structure to further develop a certain technology. This nature of following a 'logical' and predefined development of technology will result into an organization specific property, which itself contributes to the paradigm.

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Teece relates the firm's organization and the industrial structure to the technological innovation from an economical perspective. Teece introduced the notion of complementary assets [Teece 1986] as an important factor for innovation.

Uncertainty	<p>Teece refers to two kind of uncertainties, primary and secondary uncertainties, referring to Koopman [Koopman 1957]</p> <ul style="list-style-type: none"> - Primary uncertainty is due to “random acts of nature and unpredictable changes in recurring preferences” - Secondary uncertainty is due a lack of communication, where one decision maker has no knowledge of decisions and plans made by others, while these plans and decisions are relevant. <p>Teece suggests that Primary uncertainty is something that is uncontrollable, while the secondary uncertainty can be controlled to a certain extent by controlling the boundaries of the organization (e.g. by vertical integration).</p>
Path dependency	<p>This refers to the technological paradigm of Dosi [Dosi 1982] as discussed previously. This path dependency results from “a pattern of solutions to selected technical problems, which derives from certain engineering relationships”.</p>
Cumulative nature	<p>The cumulative nature originates from the path dependency, where basically incremental changes are imposed on an existing technological basis.</p>
Irreversibility	<p>Technological Progress in irreversible, as evolutionary technological development by definition eliminates older technologies in the same application.</p>
Technological inter-relatedness	<p>Teece refers here more specifically to innovation and that the success for an innovation lies in a unified approach and decision making of several organizational sub units.</p>
Tacit-ness	<p>Here Teece refers to the knowledge that is developed in organizations that cannot be made explicit. In this perspective he states that technology resides in “an organization's system and habits of coordinating and managing tasks”</p>
In-appropriability	<p>Teece argues that ownerships rights of “technical know how are ambiguous, do not always permit rewards that match contribution, vary in degree of exclusion they permit ... and are temporary”. Teece emphasizes that Intellectual Property related to technology is volatile and not free of infringement and provides temporary protection</p>

Table 2.3: Overview of the properties of technology development according to Teece [Teece 1996]

The assets basically represent the capabilities present in an organization. The presence or absence of these capabilities will determine the degrees of freedom to innovate. To put this in a technology perspective; if an organization has manufacturing capability and thus manufacturing technologies, it logically allows for technology development within the domain of that capability. Teece studied the technology development or

innovation⁸ rate and direction of different organizations and therewith as a function of different organizational parameters. Relevant for this research is to consider the characteristics of the technology development that are assumed (See Figure 2.5). Teece touches some of the fundamental properties of technology development in his studies [Teece 1996] (see Table 2.3).

In his effort to determine the factors that determine the rate and direction of innovation, Teece finds relationships between the organizational structure and incentives, the internal culture and values, the sources of finance and external linkage to networks, and the human resources and organizational capabilities. Although Teece does not make a distinction between technology development and innovation and actually exchange these terms regularly, this model may be relevant to consider for the technology development in the context of this study (see Figure 2.5).

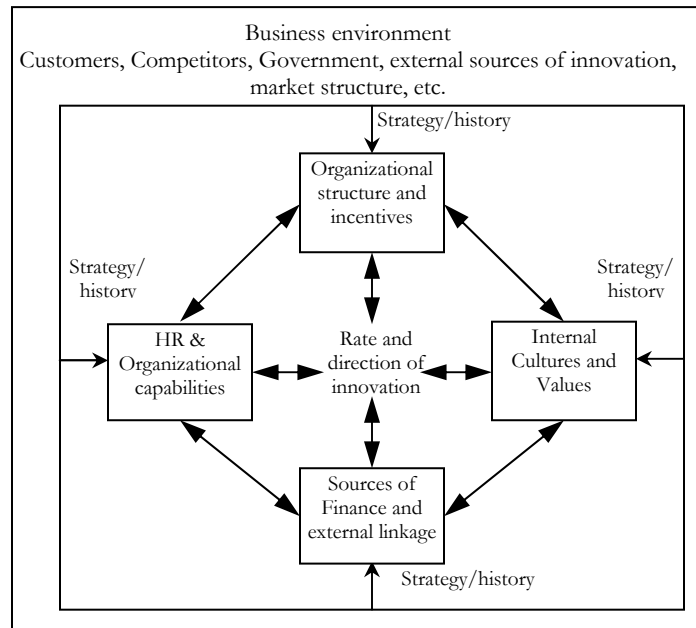


Figure 2.5: The determinants of the rate and direction of firm level innovation. (According to Teece 1996)

2.2.2 The Organizational tradition

An important contribution to the organizational tradition within the product development literature is the overview paper of Brown and Eisenhardt [Brown &

⁸ Teece exchangesis exchanging technology development and product innovation regularly. In the context of this study, technology development and product innovation are seen as distinct processes (see Chapter 5)

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Eisenhardt 1995]. In this paper, three streams of the organizational tradition are merged into a model of product development. The three streams that are identified are:

- Rational plan
- Communication web
- Disciplined Problem solving

In the following subsections these streams will be discussed as well as the contribution to Brown and Eisenhardt's generic model of product development and its implications for the technology development process.

Rational Plan

The rational plan stream is based on the notion that a successful product development is the result of a) careful planning of a superior product for an attractive market, b) the execution of that plan by a competent and well-coordinated cross functional team that operates with c) the blessings of senior management. Research in this stream initially focused on the successes in product development, but also more recent analyses of failing product developments were added to the framework. Characteristic of this research is that data is gathered in an empirical way and by finding correlations between a broad spectrum of parameters. Brown and Eisenhardt found that the theoretical understanding is in general quite limited and non-significant findings are often not reported. Anticipating which factors are relevant to the Technology development process, it is assumed that the effect of Customer and Supplier involvement is less of a factor in the technology development process. Technology development is often far away from deployment and production. Suppliers may become involved in cases where new technology developments require for example specialized materials that are not available yet. Also it is assumed that the product effectiveness can be replaced by technology effectiveness and that function and cost can be seen as the dominant factors.

Based on several contributions, adapted for the technology development process, a model of rational plan is given in Figure 2.6.

Although no particular weighting is given for the parameters in the model, the most important parameter is considered to be the intrinsic value of the product. The most successful products which were superior to the competition were able to solve problems customers were facing [Cooper & Kleinschmidt 1987]. This seems fully applicable to Technology Development as well; by creating a unique functionality superior product will be enabled that serves their users well.

Other important elements that were identified are:

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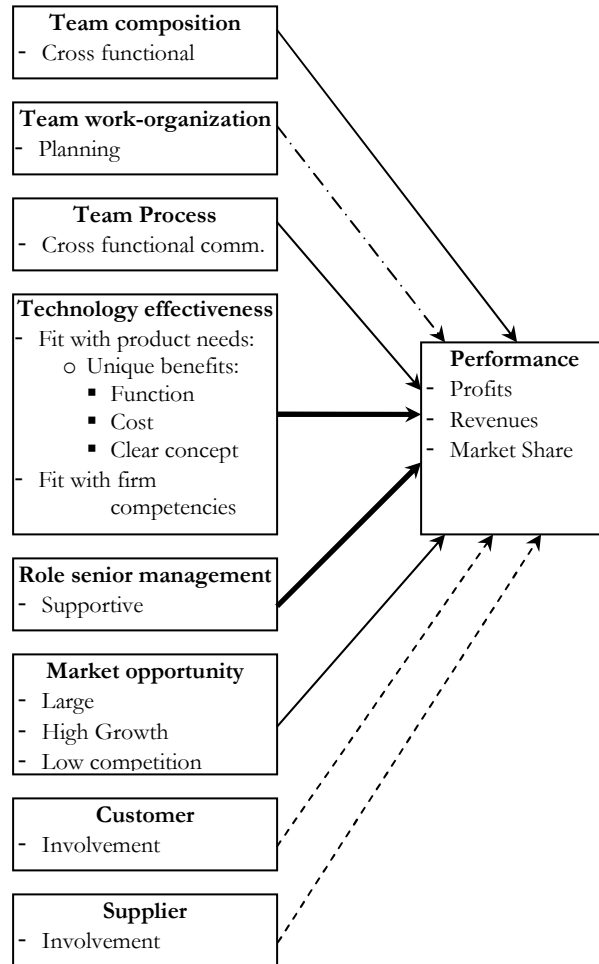


Figure 2.6: The model of rational plan according to Brown and Eisenhardt [Brown & Eisenhardt 1995], adapted to a technology relevant rational plan. The dashed arrows are expected to have less influence on the outcome technology development process, the thick arrows are expected to be more important, and the dash-dot array indicates that the evolutionary developments allow for some planning, but revolutionary developments not.

- Internal organization: especially planning of the pre-development phase, comprising defining the target market, product specifications, clear product concept, extensive preliminary market and technical assessments. Cross functional skills and their synergies with the existing firm competencies were also seen as important. Interestingly, top management support was identified as a less important organizational factor. For technology development there are some anticipated differences with these findings. Firstly the planning; one can argue that evolutionary technology developments are more easily to plan

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and despite the higher risks, this may be not that different from the product development process. Revolutionary or radical technology developments are much harder to plan and a structural planning approach is not much of a factor. Secondly, support of management is considered to be crucial for technology development as the 'business case' of technology development is fairly asymmetric

- Market conditions: products that are positioned in a large growing market are more successful, especially with a low intensity of competition. In general market conditions are found to be less important than Product value and internal organization. For technology developments there are now indications that these factors have a direct influence other than that the market conditions may influences the magnitude of technology investments.

Communication Web

This stream is based on the work of Allen. Allen studied the communication between project members and between project members and outsiders [Allen 1977]. He found that the more well-connected the members within the team and with some key outsiders are, the more successful the team is. His study focused on communication only and not on other performance parameters like in the rational plan approach. Later Ancona and Caldwell did focus on the external communication and identified that not so much the frequency of communication was a significant factor, it was the communication strategy that counted [Ancona & Caldwell 1992]. The most successful teams have a communication strategy that is effective in securing resources and gaining task related information. Consequently, the team that utilizes both political and task oriented external communications is more successful.

With respect to the internal communications it was found by Ancona and Caldwell that groups that defined the goals better, developed workable plans and prioritized the tasks, performed better. Powerful project leaders have found to have a negative effect on the group coherence; the quantity of communication goes up, but the quality goes down. Important work of Dougherty shows that different departments have different 'thoughts of world' each with its own 'fund of knowledge'; i.e., what members know and 'system of meaning'; how members know [Dougherty 1990].

These differences give different interpretations of the same information, which are apparent barriers for successful developments. Dougherty found that the absence of these barriers is not necessarily the key to a successful project, but rather the 'combination of perspectives in a highly interactive and iterative fashion'. Also an interesting result is that routine-breaking cross functional interactions have a positive effect on breaking down the barriers between members of different functional groups. A study of the team's mean tenure over time showed that teams with a growing mean tenure are increasingly successful up to a period of five years. After five years the team

becomes less successful. Figure 2.7 gives the Communication web model of product development according to Brown and Eisenhardt. This model is directly applicable to the technology development, which is a logic result noting that this model has mainly been developed in a technology development environment.

Disciplined Problem Solving

The third stream of the organizational tradition is related to disciplined problem solving. The origin of this stream lays in several Japanese product development studies, which found that autonomous problem solving by the project team, the discipline of a strong leader, strong top management and ‘overarching’ product vision results in successful, fast product developments. Imai found several management practices that are effective for fast and successful product developments [Imai 1985]:

- Strong ties with suppliers and R&D networks, providing access to specialized skills, allowing for fast lead times.
- Problem solving strategies; by involving cross functional development teams, the diversity of information and skills grew, which allows for more efficient problem solving routines. A continuous information flow created mutual understanding of partial skills of the members and added coordination to the overlapping development phases.
- Subtle management control; by balancing the ambiguity that allows creative problem solving and sufficient control to satisfy the market and strategic needs. The best performance was found where management communicated a

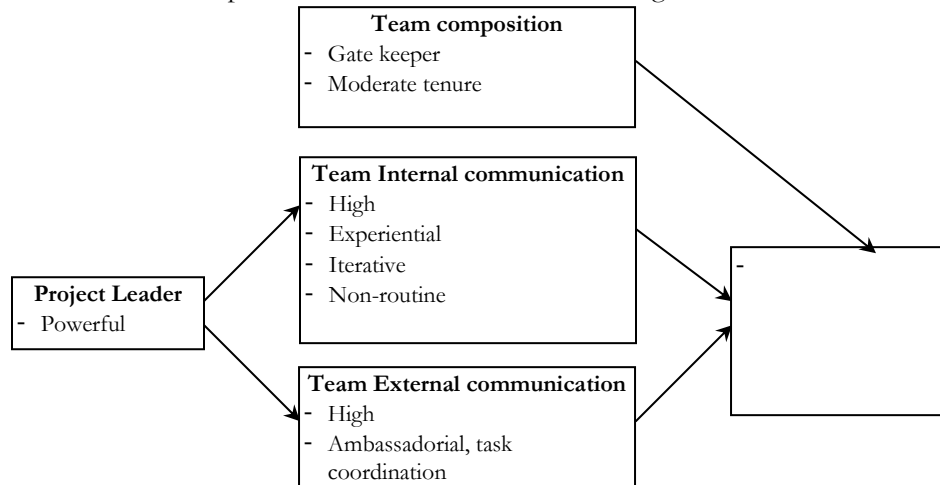


Figure 2.7: The Communication web model of product development according to Brown and Eisenhardt [Brown & Eisenhardt 1995], which is assumed to be fully applicable to technology development.

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clear vision of objectives, while simultaneously giving the development team the freedom to work autonomously on the realization of that vision.

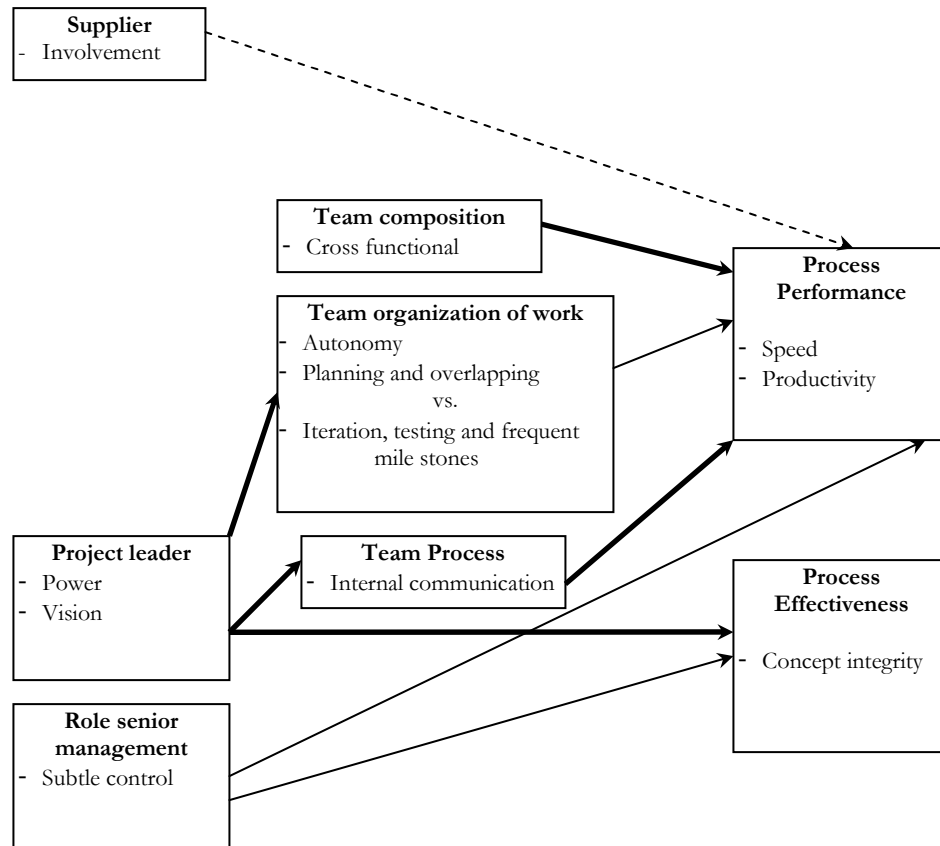


Figure 2.8: The model of disciplined problem solving according to Brown and Eisenhardt [Brown & Eisenhardt 1995], adapted for the technology development process. The dashed arrow is expected to be less relevant for Technology Development, while the thick arrows indicate relations that are considered to be more important for technology development.

In later work from Clark and Fujimoto the practice of subtle management control was further defined and explained [Clark 1987, Clark & Fujimoto 1991]. The role of a 'heavyweight' team leader, coordinating team activities on the one hand and serving as an agent for management's vision on the other, has been found very important for a successful product development. Clark and Fujimoto also related the heavyweight leader as exponent in maintaining the product integrity. Product integrity serves as a vision on the product's intended image, performance and fit with the corporate competencies and customers.

Further research by Iansiti showed that planning predevelopment had a positive effect on the speed and success of the product development [Iansiti 1993, 1995]. Finally, research by Eisenhardt and Tabrizi on the speed of product developments showed that compression of the development process did not provide acceleration [Eisenhardt & Trabizi 1996]. Teams that were engaged in experiential and improvisational product design, developed faster. Eisenhardt and Trabizi found however that product development for less dynamic markets seems to benefit from compressed development schedules. Figure 2.8 shows the disciplined Problem Solving Model of product development according to Brown and Eisenhardt. Adapting this model to the technology development process is not obvious. With respect to the vision of the project leader it is anticipated that in technology development this vision is very important as well as the communication of this vision. The reason is that it is assumed that this vision will guide the problem solving cycles of the team members, by e.g. setting the goal state. It is however questionable whether this approach is suitable for radical technology development.

Integral Model of Product Development

The model of product development defined by Eisenhardt and Brown is based on the contributions of the three sub-streams; rational plan, communication web and disciplined problem solving. The common elements within these streams together with some particular relationships related to the three sub-streams are given in Figure 2.9.

Central to the model is the product development team which, as noted by Brown and Eisenhardt, is doing the actual product development work. The model assumes a large influence from the team composition, the group-processes and the work organization on the process performance in terms of effectiveness and development speed. Cross functional teams are particular influential on the performance as the flow of information is stimulated by interaction of team members with different functional backgrounds. A gatekeeper within the team has been found beneficial to increase the external information reaching the team. The tenure of the team should be moderate; i.e. mature enough for optimal information sharing and fresh enough keep an open mind to the outside world.

With respect to the group process, frequent communications increase the information streams towards the team. It also increases the group cohesion and stimulates establishing a non-routine communication within the team. All these factors increase the information streams within the teams, which improves the performance in terms of effectiveness and development speed.

External communication increases the external information stream towards the team, which provides different view points beyond the team's view point. It also serves as a lobbying instrument to obtain more resources, more support and priority.

The problem-solving strategy factors in the internal processes that are followed to progress through the developments work. Two different methods are described; for

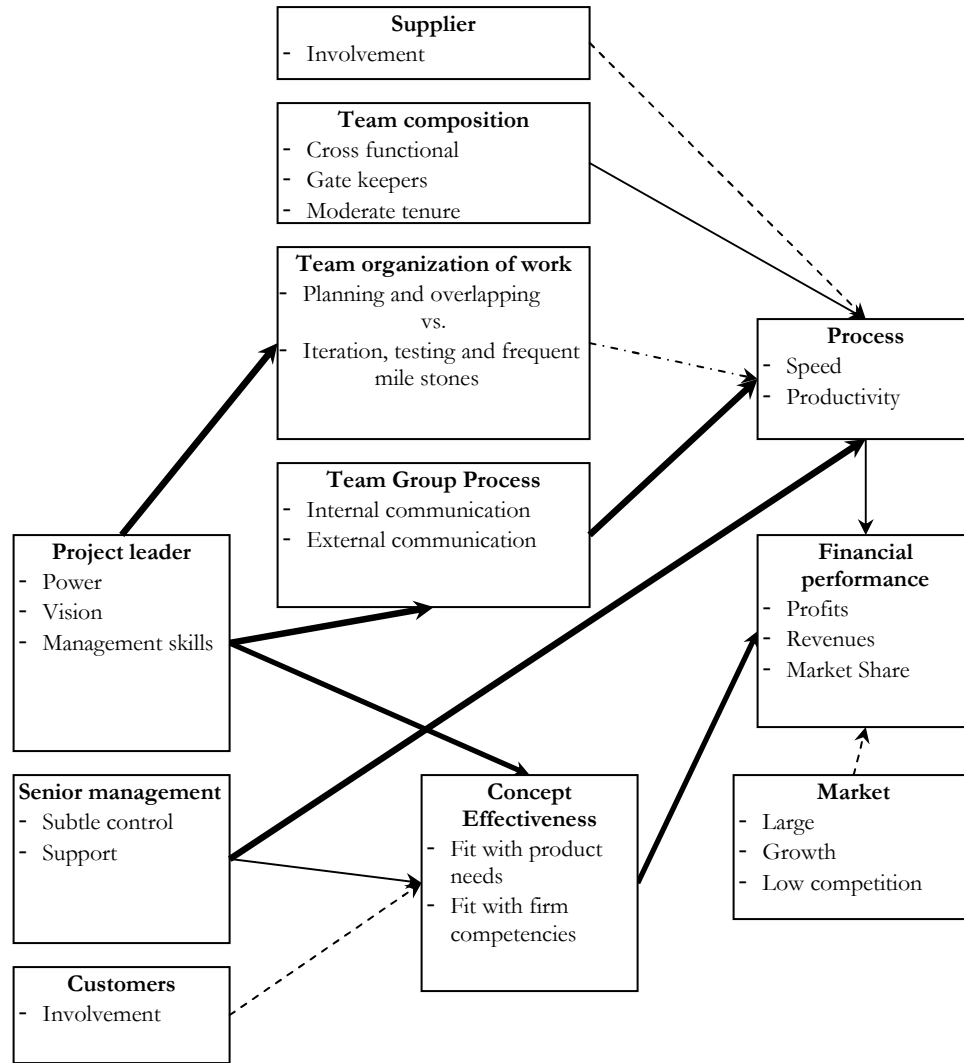


Figure 2.9: The integral model of product development according to Brown and Eisenhardt [Brown& Eisenhardt 1995], adapted to a technology development relevant model. The dashed arrows are supposed to have less influence on the outcome of evolutionary technology development process.

stable and mature product developments, extensive planning and overlapping development stages are improving speed and effectively, while for uncertain developments, experiential tactics are more effective in terms of speed and effectively. The project leader serves a specific role. Aside from managing the development tasks within the team, the project leader is seen as an agent to impose the firm's values onto the project team. A powerful project leader is found to be more effective, due to

obtaining more resources and attracting more talented team members. Moreover, well developed lobbying capabilities and ability to manage external expectations are found to be more effective. The vision of the project leader is also found to be important. By the creation of a holistic view and impose this view on to the team, guidance is provided.

Senior management support has been found crucial to successful product development processes. Support is considered not only to be providing resources, but also providing political support in the form of a favorable stance when it comes to critical decisions. From an agent theory point of view this is an important point, as there is a tension between the resource providers and the result providers [see, e.g., Eisenhardt 1989b]. Subtle control is a management model that allows the development team to be creative, however within the boundary conditions that are implied by senior management. Often the project leader is relaying these boundary conditions, sometimes captured in a vision, to the development team.

Supplier involvement is an important success factor. Especially with the increased complexity of the products, suppliers can help in terms of optimizing the development scope and reduce complexity. This improves the development and effectiveness of the development. Customer interaction is also important but the evidence is not consistent. In Table 2.4 an overview is given of the parameters, characteristics and the qualitative strength of their impact on the performance.

The applicability of this integral product development model to the technology development process may be limited to the evolutionary technology development in anticipation that revolutionary or radical developments are executed in a less structured fashion. The path dependent technology developments are less uncertain and the technology development process can be better planned. It is also questionable whether supplier and customer involvement have a positive effect on the outcome of the technology development process; the distance between the users and supplier is rather large, although it must be said that technology co-development with users and suppliers make these factors relevant.

One of the issues regarding this point is that the empirical data of Brown and Eisenhardt show that there is a weak relationship between suppliers and customers, while Hippel argues that these are very important sources of innovation [Hippel 1982, Hippel 1988]. Hippel however argues that working with lead customers will increase the gains of the innovation process, and although this is not disputed, the argument is whether for technology development a particular lead user can be identified. Therefore it is assumed that Hippel refers to product developments, rather than to technology developments when he refers to the involvement of lead users [see also Schilling 2008, p.240].

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The vision of the project leader is seen as an important factor as well as the communication of this vision as it is expected that it provide a coordinating effect on the goal states that the team adopts during the problem solving cycles (see Table 2.4).

Characteristic	Correlates to	Mechanism	Correlation characteristic
Cross functional teams	Process Performance	Functional diversity increases the amount and variety of information	Positive, Medium
Gate-keepers	Process Performance	Management of external information stream; effect less with cross-functional team.	Positive, Medium
Moderate tenure	Process Performance	Balance between efficiency of information sharing, cooperation and inward focus; optimum 5 years	Positive, Medium
Internal Communication	Process Performance	Effective internal communication increases information, increases cohesion, lowers barriers	Positive, Very Strong
External communication	Process Performance	Frequent communication with outsiders (customers, suppliers, others) increases task oriented information. Lobbying secures resources	Positive, Strong
Extensive planning and overlapping tasks	Process Performance	Squeezing the process together	Positive for stable and mature products, Negative for uncertain/ changing markets. Medium
Frequent iterations, extensive testing, short milestones	Process Performance	Focused on learning and flexibility rather than planning	Positive for uncertain/ changing markets, Weak
Powerful Project Leader	Work organization, Group processes	Obtaining more budget and more talented resources	Positive, Strong
Vision Project Leader	Product Effectiveness	Communicating the product concept	Positive Very Strong
Management Skills Project Leader	Problem solving, Communication	Small group management	Positive, Strong
Support Senior Management	Process Performance	Providing resources, (internal) funding	Positive, Very Strong
Subtle Control Senior management	Product Effectiveness	Communicating the product concept	Positive Medium
Involvement Suppliers	Process Performance	Reduction of complexity	Positive Weak
Involvement Customers	Product Effectiveness	Improves Effectiveness	Positive Weak
Process Performance	Financial Performance	Lower cost, better margins and/or more competitive, Shorter time to market	Positive, Strong
Munificent Market	Financial Performance	Large sales, competitive instability	Positive, Strong
Technology Effectiveness	Financial Performance	More attractive products	Positive, Very Strong

Table 2.4: Overview of the strength and persistence of the correlations in Brown and Eisenhardt model of Product Development. The gray entries are expected to have less relevance for the outcome of the (evolutionary) technology development, while the bold are considered to be more important to technology development

2.2.3 The integration of knowledge in product development

Aside from the two main streams mentioned by Brown and Eisenhardt, knowledge is a central concept that overlaps both the organizational and economical tradition. As the relation between knowledge and technology is evident; technology is heavily knowledge based, it makes sense to discuss the some of the knowledge based theories. Interestingly, these knowledge based views are contributed from both the economical tradition and the organizational tradition; organizational cognition, communication and learning are fields covered within the organizational science tradition and knowledge as economical asset captured in the knowledge based theory of the firm originates from the economical tradition. Both traditions seem to fuse into the broader perspective of the knowledge based view of the firm [Berends 2003]. The Knowledge based theory of

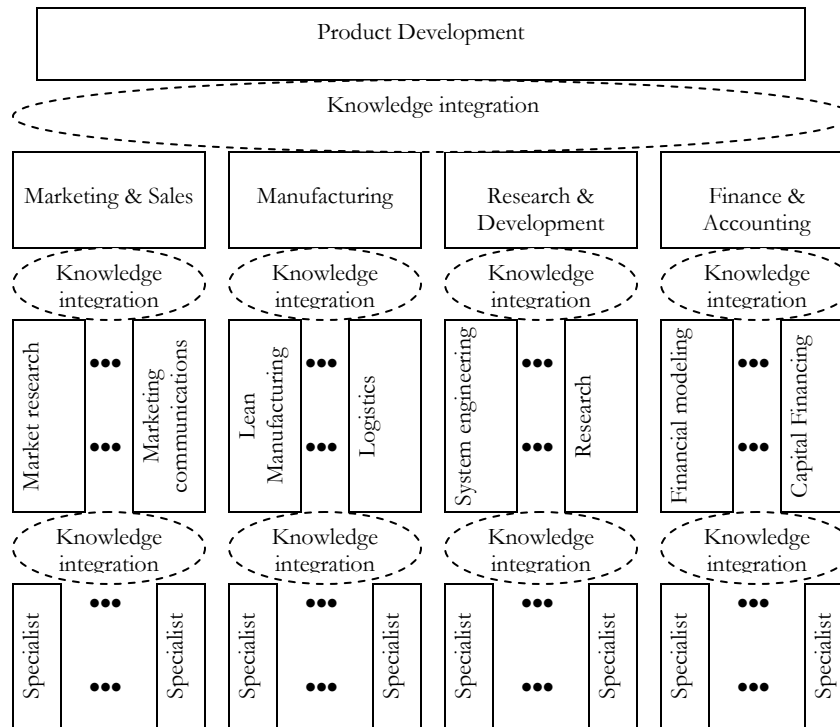


Figure 2.10: The hierarchic structure of knowledge and the knowledge integration between the four levels. Based on Grant [Grant 1996a, 1996b]

the firm is an economic perspective on the knowledge as an asset in the firm that can be processed to obtain economical growth. Knowledge is an asset that takes a qualitative aspect into account as opposed to the more traditional view on resources and human capital. The general view is that knowledge resides in humans, but that

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organizational settings can stimulate to generate [Kogut & Zander 1992] and integrate knowledge [Grant 1996] in a unique manner.

The Knowledge Based Theory of the firm basically claims that the reason of existence is related to the fact that firms can integrate knowledge in a unique manner. The generation and integration of knowledge within an organization is brought into relation to knowledge management [Weggeman 2000] [Argote 2003], organizational learning and knowledge sharing [Berends 2003]. Distinctions between information and know-how [Kogut & Zander 1992] and tacit and explicit knowledge [Nonaka 1994, Nonaka & Krogh 2009, Polanyi 1966], are used to explain different types of knowledge in an organizational context.

Grant [Grant 1996b] suggests a hierarchic structure of organizational knowledge consisting of four levels in the organizations (see Figure 2.10). At the base level specialized knowledge is held by individual specialists. These specialists interact with other specialists and this integration of knowledge leads to specialized capabilities. These specialized capabilities are integrated with functional capabilities like marketing, manufacturing and financial capabilities. These capabilities are integrated at the fourth level with the firm's cross-functional capabilities, like product development. In Chapter 1, p. 16, it was mentioned that knowledge intertwined with technology in three ways; the scientific knowledge on which technology is based, the process knowledge to create the artefact and the knowledge to determine the needs in society.

The latter one fits well within the framework of the knowledge based view of the firm (see Figure 2.10). An omission in Grants theory is the generation of knowledge in the firm which is a process that is described in detail by Nonaka and others [Nonaka 1991, 1994, 2006, Nonaka & Takeuchi 1995, Nonaka & Von Krogh 2009].

2.2.4 Change theory

Van de Ven and Poole published a paper [Ven & Poole 1995] about the theoretical backgrounds of change in organizations. They conducted a broad study and found about 20 different approaches to describe change from different fields; social studies, biological studies and physical sciences. They were able to narrow those approaches down to four main streams of change processes; lifecycle, teleology, dialectics and evolution.

The lifecycle stream uses the organic growth as a metaphor for the change process. It predicts the change on basis of sequential stages or phases that are prefigured. It assumes that the process follows a trajectory that has been determined by event in history and with that an extrapolation towards successive stages is based on past logic. The teleological stream is based on the assumption that movement can be guided towards a certain goal or end state. It assumes an envisioned end state, actions with the

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intention to reach the end state and monitoring the progress. The actions to reach the end stage are not along a predefined trajectory. This process of changes allows for creativity as methods and search paths are not prescribed. After the goals are reached new goals can be set, imposed by internally motivated directions or imposed by changing environmental conditions.

The dialectic stream assumes that progress is made by synthesis of a plurality of opposing forces, different values and different interests. It assumes that the opposing forces balance out and that the synthesis creates a new state that is different from former states. The favorable synthesis should represent a win-win situation.

The evolutionary stream is based on Darwinian principles where variation in combination with selection leads to new forms, while retention maintains previous forms. In general variation is assumed to be a random process; it just happens. Selection is assumed to take place along resource availability. Retention is balancing the process of variation and selection and represents inertia against the continuous variation and selection.

This process deals with slow and gradual changes. Gould noted that the extinction of a certain species is not well described and introduces the punctuated equilibrium theory. This assumes that slow evolutionary developments are punctuated by revolutionary

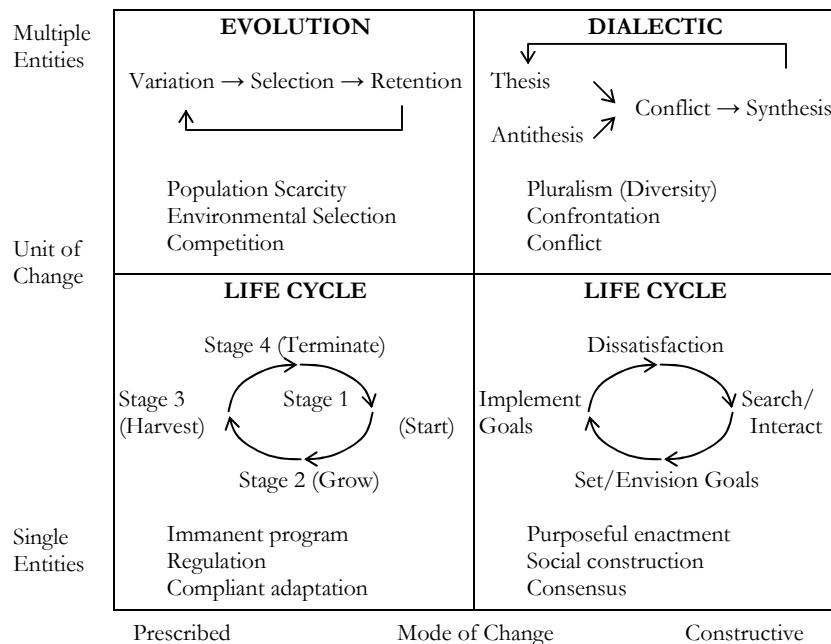


Figure 2.11: An overview of the four change processes as described by Van de Ven and Poole [Van de Ven & Poole 1995]

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periods of rapid change, resulting in the creation of a new organism and/or the destruction of existing organisms. In more detail this is described by Pettigrew [Pettigrew 1985] and also by Gersick [Gersick 1991]. A comprehensive discussion of punctuated equilibrium models is given by Gersick. The paper discusses revolutionary change theories on the basis of the punctuated equilibrium paradigm and contrasts this with gradualist paradigms, in which systems develop in “forward” directions, as, e.g., in stage theories.

The article of Gersick encompasses six levels on which the punctuated equilibrium paradigm can apply, of which four are relevant for our research: the individual level, [Levinson 1978], the group level, based on the work of Gersick herself [Gersick 1988], the organizational level, [Tushman & Romanelli 1985] and finally scientific discovery [Kuhn 1970].

In the equilibrium period the behavior of the system is governed by a certain “deep structure”. It is this deep structure that prevents revolutionary change during this period, i.e. change that would disrupt this deep structure. According to Gersick, the

Dialog box 2.3: Empirical grounded technology: no understanding needed

For centuries hardened metals were used for several tools, weapons etc. There was no understanding about the underlying mechanism and this knowledge was carried over from generation to generation. Only recently in the 20th century a fundamental understanding of metallurgy, supporting theoretical knowledge was created to provide a full understanding of the phenomena that provided this functionality.

concept of deep structure is not easy to define. It represents a set of “rules” that are rooted in the system, which determine its behavior in a stable mode of operation. It produces certain predictability because system behavior remains within a certain domain that originates from the fundamental “choices” that have been made, intentionally and unintentionally during the creation and development of the system.

2.3 Theoretical framework of technology development

Based on the theories discussed in the previous sections a theoretical framework of the technology development is derived. The framework is based on the synthesis of the similarities and differences between scientific discovery and technology development and between product development and technology development respectively.

2.3.1 Differences between scientific discovery and technology development

Popper states that a theory cannot represent the ‘truth’, at best it can be given certain truthfulness. How important is this implication for technology development? There are two reasons why this somewhat theoretical discussion leaves technology and its development relatively unaffected. Firstly, a technology works or does not work

[Polanyi 1962], and the position can be taken that the existence of a technology implies that it is 'true'. Secondly, whether the theoretical foundation of the technology is fully understood or not; 'true' is less of a concern, if the technology is a solution to a problem in a social context. So it is not necessarily related to a theoretical expectation.

This explains why some ancient technologies were available without understanding the theoretical backgrounds, solely because the problem was solved on an empirical basis rather than on a theoretical basis. In this perspective scientific discovery and technology development can coexist independently; technologies can also be based on the basis of empirical problem solving. They are however dependent if technologies are developed on the basis of solving a theoretical founded problem. It is expected that both the scientific revolution (18th century) and the industrial revolution (19th century) has resulted in a more firm dependency between the scientific discovery and technology development.

The complexity of the technologies increased dramatically and the revolutionary time scales left no room for long lasting empirical problem solving cycles. Interestingly enough scientific discoveries became very dependent on technology as well in this very same period. The modern scientific problem fields lay more and more outside the human observation abilities and normal (environmental) conditions and require technological capabilities and technologies to enable the required observations. This is one of the explanations for the long duration between new theories and the experimental verifications - the technology based verification methods and technological capabilities are often not available right away.

From the notion that all human activity consists largely of problem solving [Klahr & Simon 1999, Popper 1972, Polanyi 1962, Kuhn 1977] can be concluded that technology development consists of problem solving routines as well. This relates the technology development to many problem solving processes described in literature. Such an example can be found in Simon. As well, Polanyi discussed the distinction between science and technology in some more detail [Polanyi 1962]. From this discussion it can be concluded that the relationship between the science and technology can be described as follows:

- The difference between scientific knowledge and technological knowledge is that technical knowledge serves a certain purpose or use. This distinction draws further in a sense that science and technology mainly differ in the value judgement. Technology development is not value free as the requirement to serve a certain purpose or function is value loaded. According to Popper, Science is not value free either as fully objective observations are not possible, but the clear distinction is that scientific discovery strives to value-free actions while technology strives for actions that realise a specific function or purpose.
- Some technical fields are derived from the application of pure science to practical problems. Polanyi mentioned (in the year 1962) 'electrotechnics' and

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chemical technology as examples. Other fields relied on more empirical technology. Many of these empirical technical fields have their origin from before the scientific revolution. Polanyi stated: “Actually, up to that time [1840s] natural science had made no major contribution to technology. The industrial revolution had been achieved without scientific aid”.

- Polanyi makes a distinction between pure science, technological justified science, systematic technology development and pure technology development. Again the distinction can be related to the value loading of these activities. Polanyi points out the distinctions between science and technology that are found in society in terms of, e.g., “pure physics” and “applied physics”.

In conclusion, the main differentiator between scientific discovery and technology developments is the value loading. Problem solving is considered to be the same or, at least, very similar. This is supported by Polanyi stating that systematic technologies like electronics “can be cultivated in the same manner as pure science”. Technology development differs from science with respect to the value loading. Technology leads by definition to a functional reality and once it exists, it forms a true function in every day life.

Unlike a theory, it does not make sense to proof that a technology is false, as it existence itself serves or has served a certain purpose. Also technology does not necessarily need to be understood. Technologies may exist purely based on empirical findings and without a useful theory to give an insight how the technology provides a certain example. Does this break the analogy with scientific discoveries? Not necessarily; also science has elements of empirical data gathering and sometimes these data point in a direction that has not yet a theoretical explanation.

Dialogue box 2.4: ‘Pure science’ becomes technology

The well known quantum theory is clearly developed out of the pure scientific interest as described by Polanyi and other philosophers. Initiated by Planck and further developed by Schrödinger and others, a theoretical framework has been laid out without satisfying a direct or urgent need; just for the sake of scientific progress. Some skeptic down-to-earth practitioners may use the term ‘pure science’ for the reason that the practical application is absent. The argument here is that this can change over time. Many technological advancements make use of very fundamental scientific principles that have been discovered in the past. For example the dimensions of a modern transistor applied in the most advanced ‘chips’ are becoming so small that quantum theoretical principles are required to describe the functionality of the transistor. Within this perspective the modern transistor technologies rely on fundamental ‘pure’ scientific principles from the past. Although separated by time, the scientific progress can be seen as the front-end of the technology development.

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The purpose is different however. Where empirical data is gathered to obtain a certain understanding about phenomena, empirical principles that provide a foundation under a certain technology, do not require ‘per se’ to support a theoretical understanding. This may be one of the reasons to place technology and its development lower on the value pyramid (see Figure 2.12). Science requires a full and value-free understanding of all the phenomena, while a technology does not necessarily have to be understood, as long as it provides certain functionality. This sheds a certain light on the value-loading of technology development.

Opposed to science, the technology development has pragmatic character. Unlike science, technology has the obligation to fulfil a useful function in society. This function is related to action, following Polanyi’s characterisation of technology: ‘Technology teaches action’. One can argue that science fulfils a function in society as well, but is not related to action.

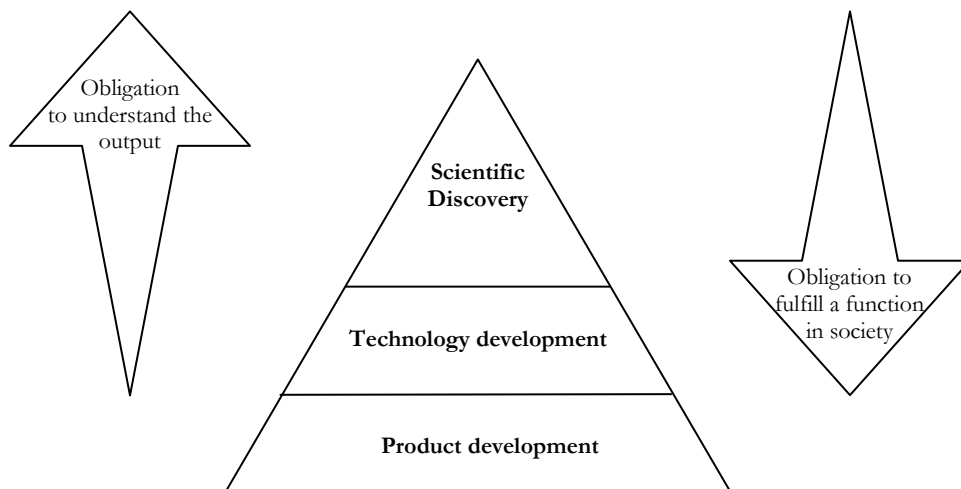


Figure 2.12 The Value-Pyramid of Scientific Discovery, Technology and Product development.

Products combining one or more technological functions, and extending this reasoning may lead to a lower position of product development in this value pyramid. The statement is that a technology either works or not implies that proving a technology to be right or wrong makes no sense. This lack of obligation reduces the scope of technology development, compared to science. In that perspective, it makes it unlogical to follow a Popperian approach here and basically excludes Popper’s deductive procedure for theory falsification from consideration for technology development.

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There is however another motivation that applies to technology development. The economical and social progress requires the development of technology, like new

Dialog box 2.5: Does pure science still exist?

The distinction between applied and pure science seems to become vaguer over time. Where Polanyi in the 1960s could point at the educational system, scientific congresses, journals and research labs, where an obvious distinction could be seen, the distinction is nowadays less obvious. Colloquiums at Technical Universities are more theory loaded, scientific congresses are less pronounced 'pure' or 'applied' and more susceptible to point at 'social relevance', industrial research laboratories contribute with 'technological justified science' to theoretical understanding. In speculation, the reasons for this fusion between pure and applied science is that:

- the increased complexity of technology required fundamental understanding that previous was the sole domain of pure science.
- there is as a tendency in society that requires that science should be 'useful'. Funding of science programs are judged on 'social relevance', which makes 'value free' or 'pure' science more difficult. Apparently, the principle of 'no taxation without representation' does apply here as well.
- the so-called systematic technologies are expanding in modern times. More and more technological fields that previously relied on empirical researches are becoming more theory loaded and moving more and more to systematic technologies.

discoveries feed scientific progress. So, by:

- a) replacing scientific progress by economical and social progress;
- b) replacing the search for better theories that provide more explanatory value; and
- c) providing more functional value

the deductive procedure for technology development makes sense.

By doing so, Popper's deductive method can be modified to a technology analog. In analogy with the scientific motivation driven by the critical mind, creating new theories that give a better explanation of the 'real' world, the technological motivation is driven en by an equally critical mind, creating new technologies that serve economical and social needs better. The following deductive method is proposed:

(a) Step 1: formal - by testing of the internal consistency of the technological system to see if it involves any contradictions in terms of the process and the expected function. This process can be a mathematical, chemical, physical or just empirical.

(b) Step 2: semi-formal - by distinguishing between empirical and functional elements; the technology developer makes the functional form of the technology explicit. This helps to define the proper functional description and gathering the proper empirical data. Likewise, analytic and synthetic elements are distinguished.

Collective Frame of Reference in Technology Developments

	Scientific Discovery	Technology Development
Knowledge	Knowledge is generated by individuals during problem solving cycles [Popper] Tacit Knowledge can direct search paths [Polanyi].	Can be based solely on tacit knowledge, Knowledge is generated by individuals during problem solving cycles.
Problem solving	Motivation: Scientific progress in terms of understanding [Polanyi]. Problem solving cycles consist of setting problem definition, goal state and search path and testing, several search strategies [Simon]	Motivation: Technological progress in terms of functionality [Polanyi]. Problem solving equal to scientific discovery.
Task Organization	Deductive procedure, formal, semi formal, comparison internal/ external, testing. [Popper]	Similar to Scientific discovery
Change	Kuhnian: Science follows a paradigm that is based on consensus in the scientific community. A crisis will result in a new paradigm Popperian: Scientific Theories are never true and are to be falsified. A scientist should always be prepared to overthrow an existing theory.	Kuhnian only. The paradigm is expected to be based on shared economical and technological beliefs, values, instruments and techniques and even metaphysics in an organizational context. A crisis where the commonality is deteriorated will result in a paradigm shift.

Table 2.5: The differences between Scientific Discovery and Technology

(c) Step 3: comparison - the comparison of the new technologies with existing technologies. Based on advancement or lack of advancement in terms of ‘technological progress’, a technology will or can be rejected or accepted. Initially this is an internal process; before a technology developer brings out a new technology, a subjective internal judgment of the technological progress will be made. If internally rejected, the technology will never be known to a broader public. However if accepted, the technology will be evaluated by others and a broader accepted technological progress will make the technology sustainable. Technologies do not necessarily replace each other, and several technologies can coexist. This situation can exist for a longer time especially if the functional differences are small. However it is in the end expected that the technology that has more functional value will be prevail.

(d) Step 4: testing - the testing of the new technology by the application of the function derived from it.

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As said Nelson, Winter and Dosi assumed that technological development is following a paradigm. Although the economists use this concept to explain the technological development within an industrial sector in a more macroscopic view, the question is whether the technological development in an organization follows a paradigm as well. From Kuhn's theory, the paradigm of scientific development is based on the consensus of a scientific community that can be altered if cumulating evidence appears which breaks down this consensus.

Leaving the paradigm is not a clear cut decision but is based on a growing collective perception that the old theory does not hold and new theories need to be developed. The question is whether this translates to technological paradigms. The evolutionary economists, by definition, are looking at gradual changes in the technological development in an economical perspective and gradual changes do typically not match with paradigm shifts.

However, the earlier discussed value loaded character of technology does not require the open ended, consensus creating or destructing debates to change paradigms. It is suggested that actors within a confined technology creating organization can decide to shift technological paradigms as long as there is a justification that new technologies will increase technological progress in terms of function and cost.

Nevertheless it is expected that the motivation to shift paradigms will be balanced by the equivalent of the Kuhn's disciplinary matrix [Kuhn 1970b] within the organization, comprising 'the shared economical and technological beliefs, values, instruments and techniques and even metaphysics. In summary the differences and similarities can be expressed in a cross sectional view of the concepts knowledge, problem solving, task organization and change. These processes are summarized in Table 2.5.

2.3.2 Differences between product development and technology development

The model of Grant which shows that in an organization knowledge is integrated at four levels may be similar for technology developments. There are a few differences however. Although it is recognized that knowledge integration is part of the technology development process, it is expected that this will happen at least initially more on a team basis where specialists with different backgrounds share and integrate knowledge. These specialists are in the meantime generating knowledge, which is considered as one of the main processes in technology development.

In this perspective it is unsure whether Grant's model fits unchanged to the technology development process. Where suppliers and customers play an important role in product development, in technology development there may be some interaction with suppliers of specialized materials and components to support the technology development process. Like with product development this may reduce complexity of the technology development. From a knowledge perspective knowledge is exchanged with those suppliers and often this knowledge exchange is driving developments at the

Collective Frame of Reference in Technology Developments

supplier. Moreover, knowledge is exchanged over technology or scientific networks. These networks may connect competitors, governmental institutes and universities.

The problem solving cycles in the product development model are not very clear. Iterations assume that there are cycles involved and extensive testing is in general part of the cycle. The model for uncertain and dynamic markets seems to give the best fit for technology developments; in general the uncertainty is high, and using planning is not helpful. Several iterations, extensive testing and short milestones seem to be more appropriate.

The change process in product development is mainly evolutionary. The product development model assumes that product development fits to the existing competences within the organization, which assumes that a technology paradigm is followed. As technology follows a paradigm, the organization will strive to manage their continuous product developments as long as possible within the technology paradigm. However, at some point the organization has make a paradigm shift as the

	Technology Development	Product Development
Knowledge	Can be based solely on tacit knowledge, Knowledge is generated by individuals during problem solving cycles.	More emphasis on integration of knowledge; multi-disciplinary teams integrate knowledge in the product creation process
Problem solving	Motivation: Technological progress in terms of functionality [Polanyi]. Radical: Problem solving equal to scientific discovery. Evolutionary: More disciplined problem solving	Disciplined problem solving; cross functional teams solve problems guided by a strong vision. [Brown & Eisenhardt 1995]
Task Organization	Radical: Similar to Scientific discovery Evolutionary: Planning, limited distribution of tasks, Limited milestones	Strong planning; distribution of tasks, multiple milestones
Change	Kuhnian only. The paradigm is expected to be based on shared economical and technological beliefs, values, instruments and techniques and even metaphysics in an organizational context. A crisis where the commonality is deteriorated will result in a paradigm shift.	Incremental change process, path dependent [Dosi 1988], Change mainly by integrating knowledge [Grant 1996].

Table 2.6: The differences between Technology and Product Development.

available technologies can no longer support the product requirements and a paradigm shift is required to secure further product development cycles. This aspect is not particularly discussed in the model of product development. Following a paradigm, punctuated with paradigm shifts is very similar to the punctuated equilibrium theory of

Chapter 2: Theoretical Framework

Gersick [Gersick 1988]. A revolutionary, punctuated technology development implies a change of the organization as its deep structure will significantly change.

This is very different from product development, where the deep structure will only gradually change. Where radical technology development processes often require organizational changes, the product development process can more rely on the existing competencies within the organization.

At a deeper level of the technology development process it is expected that teleological change processes play an important role in the problem solving cycles as described by Van der Ven and Simon.

The organizational tradition is very much focused on the process side of new product development. The work of Allen has a very direct connection to technology development as most of his work was centered upon R&D processes in an industrial research laboratory [Allen 1977]. It is expected that technology development also will benefit from effective technologies, strong, skilled project leaders with vision and a supporting senior management. The internal communication to disseminate the vision is expected to be equally important.

The performance of technology development is difficult to capture in the financial parameters as proposed in the product development model. Due to the fact that only a few technologies make it to an application, it is a process that is very hard to manage. The success rate of technology development is reported to be low at typically 1 or 2 success out of 10 attempts [e.g. FETC 1997].

An important measure of technology is the product value and competitive value which the technology contributes. It is suggested to use the progression in value as a measure for the success of a technology. Furthermore the technology development process in terms of speed and effectiveness is expected to be very similar.

The last difference is the involvement of the customer. Technology development needs input related to long term product plans. In general customers do not look five years ahead. It is assumed that the organization needs to be proactive by monitoring trends in markets and select technology development efforts on basis of a longer term vision.

In summary the differences and similarities can be expressed in a cross sectional view of the concepts knowledge, problem solving, task organization and change. These processes are summarized in Table 2.6.

2.3.3 Towards a framework for Technology development

From the analysis about the similarities and differences between technology development and scientific discovery and between technology development and product development, a cross section that covers the majority of theoretical considerations related to the development of technology is deducted. The following fields are identified as particular relevant.

Collective Frame of Reference in Technology Developments

- **Technology development as a knowledge process:** whether it is deduced from the scientific discovery field or the economical and/or organizational tradition in the product development literature, knowledge is an important factor in technology development.
- **Technology development as a distinct organizational process:** although sparsely described in literature, technology development is a dedicated organizational process which requires unique management techniques.
- **Technology development as a problem solving process:** technology development consists of problem solving cycles to find technological solutions. During these cycles the individual and/or groups of individuals are searching for technical solutions to predefined goals.

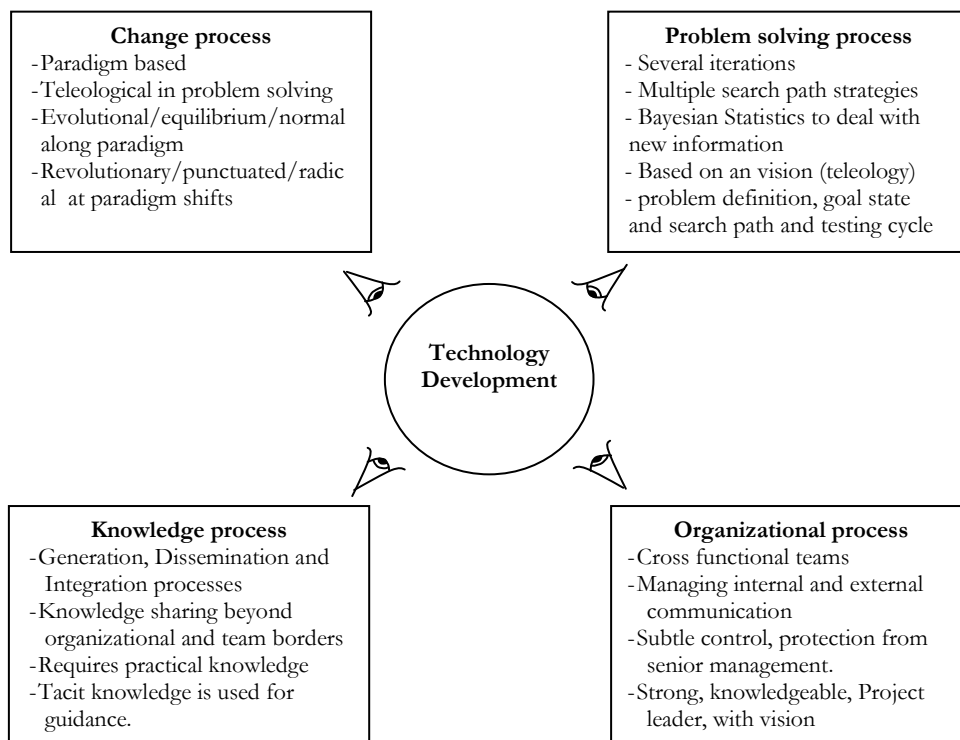


Figure 2.13: Four views on the technology development process.

- **Technological development process as a change process:** an extensive number of publications have been written on technological change, especially from an evolutionary economic perspective. The extent of this change process is related to either following the technological paradigm or exchanging the

Chapter 2: Theoretical Framework

technological paradigm. This is considered to determine the difference between 'normal' technology development and 'radical' technology development. The punctuated equilibrium theory describes these two regimes were in time, periods of normal technology development, i.e., following an existing paradigm, are punctuated by periods of radical technology development, i.e., shift to a new paradigm.

Given the questions and the answers this research wants to contribute, a few angles have been chosen to describe the majority of the relevant aspects (see Figure 2.13).

Technology development as knowledge process

In the last decade a lot of decennia numerous advances have been made in the establishment of knowledge as an important asset of the organization. The relationship of knowledge and technology is considered to be obvious; technology can be seen as the embodiment of knowledge, indifferent whether it is scientific, explicit or tacit knowledge. Just theoretical knowledge is not enough to obtain a technology; it requires practical knowledge or 'know how' to create a 'construct' that embodies the theoretical principles. These considerations imply that technology development is a knowledge intensive process.

From the economical perspective it is learned that the technological solutions originate from the knowledge base in the organization. This knowledge base is not static and technological progress requires that the knowledge base is sufficient to support technological development. Hence, in an organizational context, knowledge is generated [Nonaka 1994], disseminated [Berends 2003] and integrated [Grant 1996]. Furthermore, technological knowledge is generated by problem solving cycles, alike scientific knowledge [Popper 1970].

The generation process is considered to be an individual process [Popper 1970, Polanyi 1962, Nonaka 1994], while tacit knowledge is thought to play a role in coordinated activities. Polanyi considers tacit knowledge responsible for the implicit coordination between groups performing complex tasks like scientific or technological research. How this coordination works is not entirely clear. Nonaka uses the tacit knowledge phenomena to explain the knowledge generation process.

Knowledge integration and dissemination are considered to be group-processes, where individual knowledge is shared and integrated [Grant 1996]. Through networks, engineers and researchers are connected over the borders of their organizations to individuals with similar backgrounds and who are working in the same field. In regular gatherings, like conferences, these people exchange knowledge and discuss generic problems and challenges.

Collective Frame of Reference in Technology Developments

Technology development as change process

Technology developments, especially developments that require a paradigm shift, require organizational change. A few change mechanisms seem to be particularly relevant. The punctuated equilibrium theory as described by Gersick in an organizational context [Gersick 1991] gives a description of the organizational change in general.

As argued previously, the notion is that technology developments follow a paradigm most of the times, but, at particular times, a paradigm shift occurs. While the following of a paradigm can be identified as an equilibrium state where the organization gradually changes, the paradigm shift can be identified with a punctuated process of radical change. So technology development does not necessarily always involve significant changes for the organization; the new technological option may be close to already known ones which imply that the uncertainties in the development process may be limited, and that no major investments to change the technical infrastructure of the organization are required.

In such cases a gradualist paradigm may be used to describe the changes and some type of stage gate system may be used to manage the development process. However, if the new technology is radical, the punctuated equilibrium paradigm may be better suited to describe the changes and other systems may be needed to manage the development process. Although not specifically discussing the development of radical new technologies, the model developed by Van de Ven, Polley, and Garud [Ven et al 1999] essentially also uses a kind of punctuated equilibrium model in their “innovation journey”.

Brown and Eisenhardt [Brown & Eisenhardt 1997] argue that, opposed to the punctuated equilibrium model, organizations rather seem to change in a constant pace. Brown and Eisenhardt refer to the product development process as a continued process which is not punctuated. This assumes that technical paradigms are followed or gradually changed.

At a deeper level of the technology development process it is expected that teleological change processes play an important role in the problem solving cycles as described by Ven and Simon.

Technology development as problem solving process

Knowledge generation in connection with developing new technologies is ultimately a process that takes place in the human mind, which is linked to human problem solving. In technology development this individual generation process is influenced by group processes and in the context of an organization. The goal state in problem solving cycles is very similar to the teleological change process as described by Van de Ven [Ven 1995]. Therefore it is expected that this process plays an important role in steering the problem solving cycles.

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It is assumed that the problem cycle is part of a wider decision making process. This process is related to the problem definition, goal state definition, the search strategy, and test strategies. These decisions are made on the basis of existing information and a stream of new information originating from the problem solving itself. Bayesian statistics can be used to deal with this new information.

Technology development as organizational process

The justification for the assumption that technology development is a distinct organizational process can be based on a few contributions in literature. Recently, Cooper pointed out that technology development processes are different from other development processes and “[deliver] new knowledge, new technology, a technical capability or a projects”. Also they “... include fundamental research projects, science projects, basic research, and often technology platform projects” [Cooper 2006]. According to Cooper these projects lead to “multiple commercial projects, new product or new process development”, suggesting that the technology development process is a separate process.

Furthermore, according to Cooper, technology development projects are rare, so it is difficult to learn doing them well and typically it takes a lot of resources and time, the projects are uncertain and do not provide an immediate financial result. Because of this they are fragile, easily killed by a management often under pressure to deliver short term results.

The product development model of Brown & Eisenhardt gives some valuable insight into the importance of cross functional teams, the internal and external communication, and the quality of the project leader and the role of senior management. These characteristics are assumed to be more or less valid for technology development as well. Concerning the project leader, it is expected that additionally the project leader should be knowledgeable, analytical and visionary in order to produce proper problem descriptions for the team. Aside from a supportive or facilitating role of senior management, the protection of the fragile technology development project is very important.

2.4 Literature map

Figure 2.14 shows a literature map of the sources that have been used to construct the theoretical framework of technology development in the context of this research. The map shows the three domains: scientific discovery, technology development and product development on the vertical axis. On the horizontal axis the economic and organizational traditions are distinguished. These two traditions extend into the technology development domain, but do not enter the scientific discovery domain. The entity knowledge is positioned between the two traditions and covers all three domains. Innovation process is overlapping the technology development process and the product development process.

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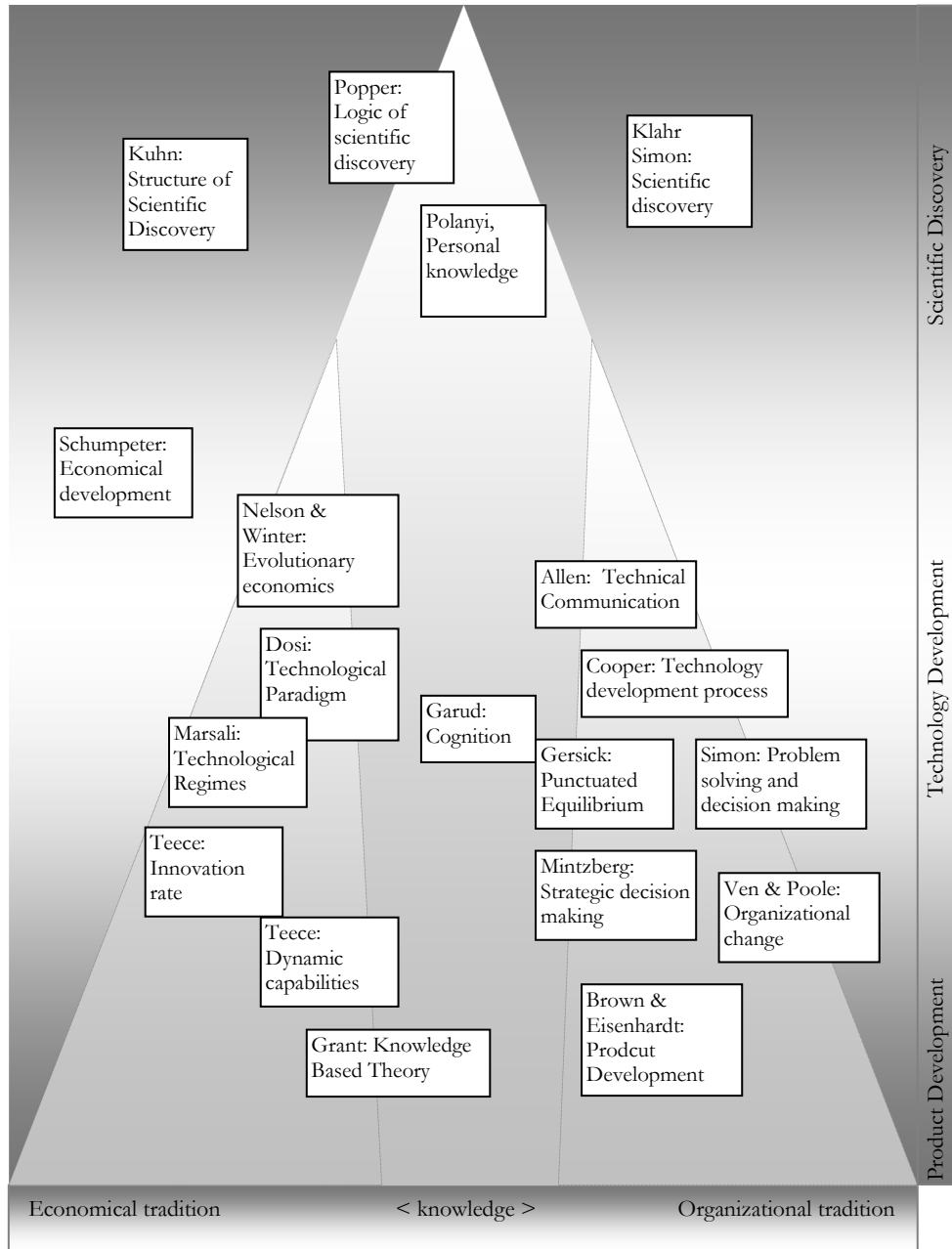


Figure 2.14: A literature map of the literature that contributed to the theoretical framework

“Technology development projects are a special breed: although they represent a small portion of effort in the typical firm’s development portfolio, they are vital to the firm’s long term growth, prosperity and sometimes even survival”⁹

Chapter 3: Description of the technology development process

3.1 Technology development process

The literature on Technology Development is mainly related to New Product Development, where the introduction of new technologies into a new product design has been described in several papers. The focus in this stream of literature is not so much on the origin of the technologies, but more on the benefits of developing a product with unique functionality, outperforming existing product offerings. Wheelwright and Clark introduced the ‘funnel’ model to show that several options are available prior to the development of a new product (see Figure 3.1) [Wheelwright & Clark 1992]. Selecting and organizing these options is associated with product pre-development, which is not necessarily technology development. The pre-development phase results in a convergence towards a solution that takes place before the options

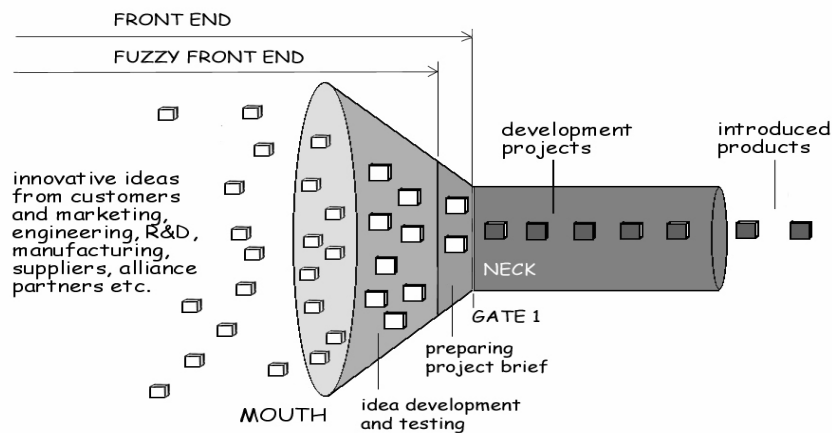


Figure 3.1: The Fuzzy Front End of main stream NPD [Wheelwright & Clark 1992, adapted by Van Aken & Nagel 2004]. Here the Fuzzy Front End is seen as the beginning of the Front End, which ends with the preparation of the project brief.

are implemented in the actual development phase. This implies that there is a focus within the pre-product development phase, towards the creation of design blocks that

⁹ Robert G. Cooper in ‘Managing Technology development projects’ [Cooper 2006]

are thought to be the best option available for the new product. Unfortunately the funnel model does not reveal much of the technology development itself. In the pre-product development phase different existing technologies are benchmarked towards a specific set of requirements and some critical design blocks are developed and tested prior to implementation into a product [Boersma 1994]. 2001].

Van Aken & Nagel and others [Van Aken & Nagel 2004, Koen 2002, Kim & Wilemon 2001] have discussed the fuzzy-ness of the stages that are prior to the (pre)-product development. For quite some time attempts have been made to provide a systematic approach to deal with new ideas and determine the needs for new technologies [see e.g. Baker 1967, Teubal 1996].

Also, some efforts have been done to make this Fuzzy Front End of product development less fussy by quantitative methods, which are basically based on a betting game approach [Reinertsen 1999]. It is however argued that more can be done to understand this Front End and the processes that play.

Therefore it is interesting to consider a flow that connects technology development to new product development and define a less fuzzy and more detailed front-end. Within this effort a technology development flow will be considered that incorporates four stages, starting with the creation of technology down to the implementation of technology into a product. The technology development flow is proposed based on the following considerations:

- The possibility for a new technology emerges at some point in time, either as a result of a scientific or a technological discovery. While the first is related to purely theoretical principles, the latter can be related to theoretical and/or empirical principles. For both discoveries certain functionality emerges, that was either not known before or was known before but based on a different principle.
- Technology is generated by the creation of an artifact that contains the function related to that technology. This artifact is a logical consequence of exploiting the function for a certain application or use.
- A selection process within the organization comprises the evaluation of the function and enabling a comparison with other technologies. The value of the function is determined by the (perceived) value that user will attach to the function.
- Often several technologies are combined in order to combine functions. To obtain data about how existing and new technologies interact, an artifact is created with the aim to study the integrated technologies and their combined functions.
- Once the technology is sufficiently proven and appropriate for application, it will be deployed into a product.

Figure 3.2 shows the ‘Technological Option’ or TO-model, with the five stages of discovery, generation, selection, integration and deployment of technological options.

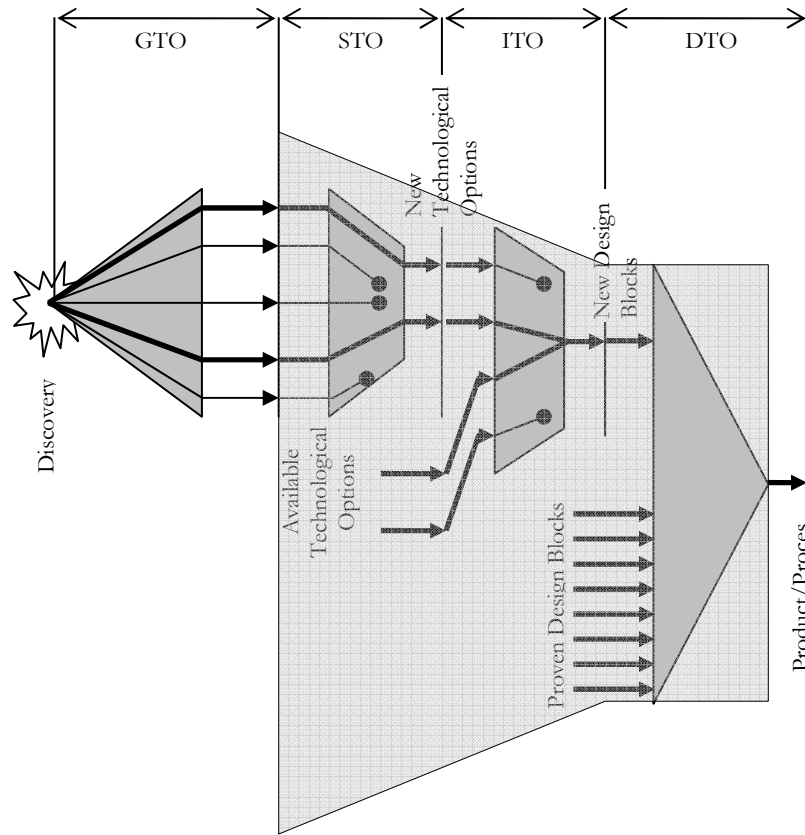


Figure 3.2: The ‘TO-model’ of the technological options prior to the creation of a product. The light gray overlay shows the Funnel model of Wheelwright and Clark [Wheelwright & Clark 1992].

The schematic representation shown in Figure 3.2 can be seen as particularized version of the funnel model in which the several technological options and design blocks converge into a new product or new production process. Figure 3.2 must not be seen as ‘stage gate’-like proposed by Cooper [Cooper 1990, 2006] development process; it indicates the life cycle phase of a certain technological option and it represents a decision process related to the availability, feasibility and maturity of the technological options.

Upon availability, the technological option can be chosen for integration into a design block. If this design block has a high risk associated with it, for example because it is based on a new combination of technological options, a pre-product development

phase can be planned to de-risk the integration of those options. Once proven, these design blocks can be selected and integrated with other (existing) design blocks to form a new product or production process. In this perspective, several technological options are integrated into design blocks that together form the product or process, and a single option can be seen as one of the many options that contribute to the functionality of the product. Figure 3.2 shows that the technological options and design blocks have different stages of maturity and different lifecycle phases.

In general a new product consists of both new and mature options in order to manage the risk of the development. The Japanese product development practice is especially known for a stepwise approach to introduce new technologies into new products and where new options and blocks are gradually blended over several generations (see e.g., the Toyota Product Development model [Morgan & Liker 2006]).

In the Generation of Technological Options (GTO) stage a new technological option is discovered. This discovery is not necessarily the same as a scientific discovery as described in Chapter 2, but it represents the event that it becomes apparent that certain properties result into a functional advancement. In some cases the coupling between the scientific discovery of a property is very closely related to the functional advancement but, in other cases, the technological option is generated based on empirical processes, like trial-and-error.

In Chapter 4 a case is discussed where a scientific discovery coincides with the revelation of the functional potential; the scientific phenomenon was revealed by the switching from a metal state to a transparent state, which results into a functional switching mirror. These technological discoveries are not restricted to Technology Intensive Organizations (TIOs) but happen often where ‘science is practiced’ and are offered to TIOs as technological options in various stages of development.

Wherever the GTO stage is executed, it incorporates the process of technology generation in which an observed or a theoretical predicted phenomenon is proven to be controllable by use of an artifact, device or construct. A well-known example is the first transistor, invented by researchers of the Bell Laboratories in 1947 (see Figure 3.3). This device is conceptual and looks not at all like the transistors that were applied years later in radios and other products or currently in the integrated circuits (ICs).

The conceptual device incorporates a distinct function that is revealed by stimulation of certain controls that are present in an experimental setting. In this stage, a theoretical framework is formed around the phenomenon by intensive experimentation, providing the understanding of the (physical) processes at play. The theoretical framework should contain sufficient knowledge to predict the phenomenon in all relevant environmental conditions which gives a first order indication of the applications. A successive step in the GTO stage concerns a more specific study of the device and the basic performance of the functionality.

Chapter 3: Technology Development Process

Mapping the characteristics of the technological concept on which this device is based provides understanding about intrinsic performance such as lifetime issues. An intriguing question for research labs is how much effort is required to obtain a technology that is mature enough to be applied into a product. This is difficult because a paradox arises at a certain point: on the one hand there always will be an uncertainty whether a technological concept will be suitable to obtain certain functionality, while on the other hand the integrity of a technology can only be tested when it is applied in a certain application.

It is a costly process to make one or more prototypes that are proved to be both functional and suitable for manufacturing and implies that the firm has to take a strategic decision to further develop a certain technology further.



Figure 3.3: The first solid-state transistor, which has hardly any resemblance with the later transistors as applied in radios and television sets. (Courtesy of Bell Labs)

Once the technological option is created and it has been decided that it has enough potential to become an option for a new product, it enters a stage in which the technology is selected for application; i.e., the Selection of Technology Options (STO) stage. This stage is positioned at the entrance of the funnel depicted in Figure 3.1. Considering the example of the transistor, in the STO stage the functionality is recognized to be relevant for a certain application; for example a radio. By selecting the technological option for this application, not only are certain parameters optimized for the required function, but also particular properties like lifetime are evaluated. This tailoring is important as certain applications have special needs and in this phase it is often unknown how a new technological option behaves under certain conditions or

use. Optimizing the technology for a certain application allows for benchmarking several technological options that are potentially available. In the case of the solid state transistor, it required a certain level of maturity of the technology to be considered as a replacement of the vacuum tubes.

The Integration of Technological Options (ITO) stage, or pre-product development stage, is positioned in the second part of the funnel model. In this stage the technological options are integrated into critical design blocks. This stage is similar to the notion of architectural innovation with the difference that old and new technologies may be combined and not just old technologies used. [Burgelman 2001, p.448]

The ITO stage will reduce the risk of incompatibilities between technological options. So, once the transistor was developed further and became mature enough to justify its application, some circuit designs were made to evaluate the performance of the transistor as an integral component for a circuit. Although it seems that the STO and ITO stages are single events in time, in practice these stages include extensive research and development of prototypes in different forms, close to the possible application. This development of prototypes often requires serious investments and can take years of effort.

To reduce the risk, sometimes one or more alternative technologies are applied in prototypes, which are benchmarked to issues like functionality, reliability and manufacturability. For some technologies this last item is not evident; the STO-stage can even contain the development of the process necessary to produce a product based on this new technology. Back to the transistor example: a semiconductor manufacturing process was developed in order to manufacture the transistors in high volumes. It is not uncommon that a costly experimental production facility is built to validate that a new technology can be applied from a production perspective. Once all these hurdles are taken, a technology can be selected to be applied into a new product.

This stage is the actual product development stage or Deployment of Technological Option (DTO) stage and brings the actual technology option to the market. In this stage, various design blocks containing new and existing technological options which are integrated into a product that satisfies the requirements for a specific application. It should be noted that the transitions between the stages are not always smooth and issues can occur - especially from the STO directly to the DTO stage [Burgelman 2001, p. 605]. The ITO stage is specifically designed to make this transition smoother as discussed by Boersma [Boersma 1994] and also by Iansiti and West [Iansiti & West 1997].

3.2 Product development and technological options

In general, product development teams decide on a suite of technological options where performance, functionality and risks are considerations for the selection of these

Chapter 3: Technology Development Process

options. The risks do not so much relate to the risk of implementing the technological option itself, but integrating several options into a product comes with a certain risk that needs to be managed. These integrating activities require specific skills which are considered to be different from the development of the technology options and allow for a distinction between technology development and product development.

Where the development of a singular technological option is considered to be the domain of technology development, the integration of these options in a systematic approach is considered product development. In this perspective the relation of technological options and a product concept is best illustrated by observing a functional taxonomical scheme of a product. This taxonomical schedule is snap shot of a certain product in time and reflects the choices at a certain time during the product development of the product. In relation with case B described in Chapter 4, a Single Lens Reflex (SLR) camera will be used as an example here (See Figure 3.4).

Figure 3.4 shows some of the design options that are related to an SLR camera, and although only one branch with only a few levels is depicted, it already shows how many design choices are available. The solid arrows show the actual choice, while the dotted lines show the alternatives. It also shows that technology is present in many details of the product and that the integration of all those options is a complex design task. All these options are evaluated against product requirements and the choices are made in terms of availability, risks and costs.

This analysis is very similar to the analysis of Petroski, who showed design consideration for many products [Petroski 1996]. He also showed how one design, with certain drawbacks, results in an improved design. For the paperclip he showed that these improvements or apparent improvements spans over more than 100 years. This process does not necessarily result in the best product solution. Some options in Figure 3.4 are not available or ready to be deployed even though there are reasons to assume that these options offer better performance.

Conversely, an organization is limited by the availability or access to certain technology blocks which may result in playing only in a certain niche market where the fit between the needs and the technological options justifies market presence. Also, the available supporting technologies matter: Petroski showed that new technologies in the design process of the Boeing 777 not only had a significant impact on the development time, but also on the quality of the product [Petroski 1996, p.120].

Some critical technology options are required to enable another technology block; for example the development of the bulk filter technology (See Case Study B, Chapter 4), allows for the development of a high performance Infrared (IR) cut off filter technology. As long as the development of the option does not deliver a mature one, choosing an IR-cut off filter is not a consideration.

Moreover, the development of an actual product with such a filter will still require time and needs pre-development activities before it can be integrated into a product with an

acceptable risk factor. One of the considerations is that once the concept is proven for one set of conditions, it is not trivial that the concept will work under another set of conditions. This implies a certain risk, which can affect the progress and planning of the product development process. In this perspective it is assumed that pre-development activities are deployed to de-risk the product development, by creating

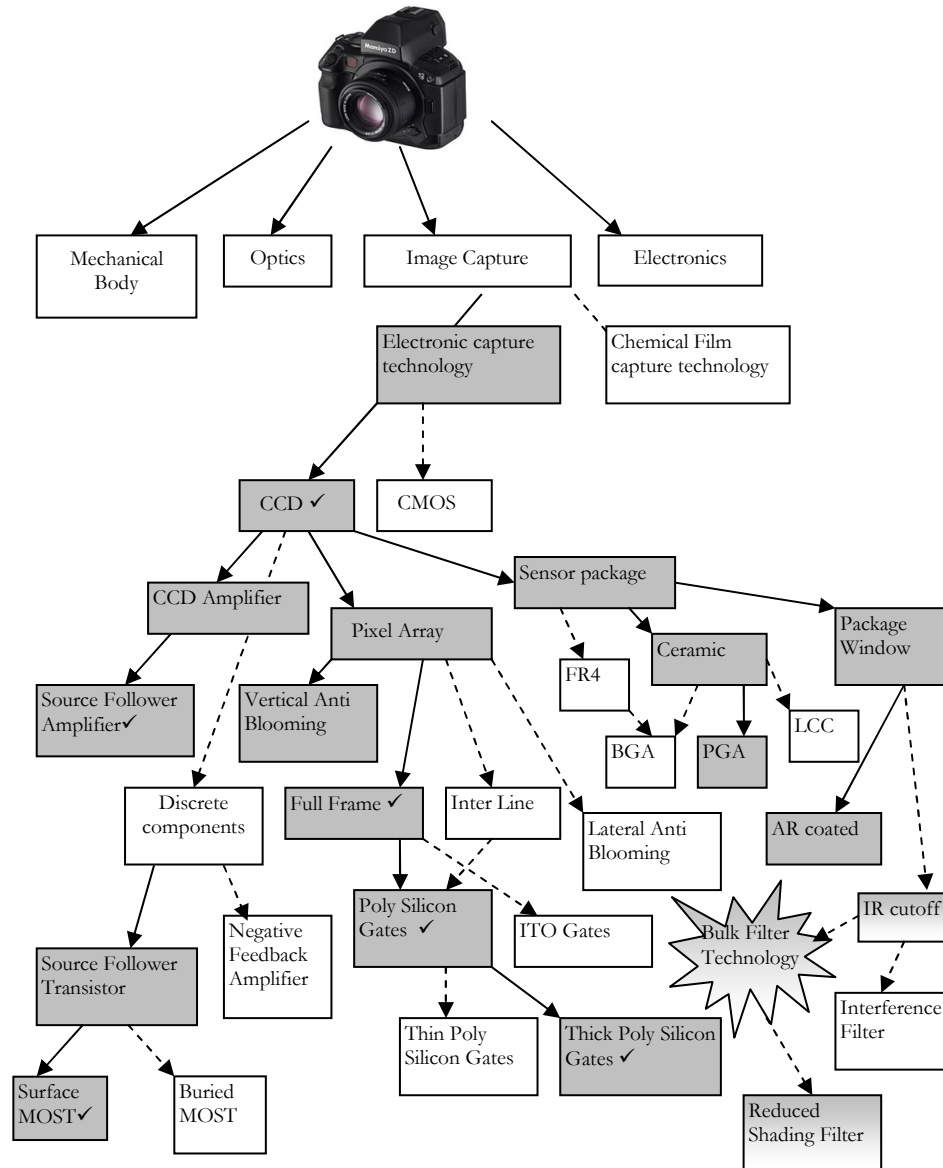


Figure 3.4: A taxonomic scheme of some of the design options of an SLR camera. Only one branch is depicted here; the image-capture functions. Some of the options are enabled by specific technology advancement; e.g. development bulk-filter technology (see Case C, Chapter 4).

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specific design blocks that are new combinations of technological options.

Table 3.1 gives an overview of the Technology, Product Pre- and Product development activities and the relative distinctions between those processes. From Figure 3.4 another feature can be observed as it shows a certain path dependency. This path dependency is aimed along the technological options that are available within the organization. This intra-organizational technological paradigm shows the path of ‘safe’ technological options on which the organization bases its products.

Activity Characteristic	Technology Development	Product Pre-Development	Product development
Main function	Creation of Technological Options	Creation of Design Blocks	Creation of Product concepts
Deliverable	Technology Concept, tested for functional performance and functional reliability	Design Block, by integrating several technology options	Product Concept, by integrating several proven design blocks
Main driver	Creation of Technology portfolio	De-risking of product development	New product Development
Planning Tool	Technology Roadmap	Design Block Roadmap	Product Roadmap
Typical forecast window	5-3 yr	3-2 yr	<2yr
Management Domain	Technology Management	Product-Platform Planning	Product Planning
Goal state set by	Function requirement	Design Block requirement	Product requirement

Table 3.1: The differences between technology development, product pre-development and product development.

Although from a macro economical perspective several organizations seem to follow a generic technological regime, a closer view will show that every organization has somewhat different approaches, resulting in different technological options. From this observation two conclusions can be drawn; Technology Intensive Organizations differ in terms of technological options that are deployed, and the TIOs are bound by the availability of technological options, which results in a path dependency. It also shows that TIOs do not really compete with exactly the same technologies, but they compete with a portfolio of technological options that provide about the same functionality, but often based on different concepts.

These differences can be explained by previous choices which have been made in a similar manner to the taxonomical scheme given in Figure 3.4. In Figure 3.5 a taxonomical scheme of a solid state image sensor is given that shows the technology options that are available within a given organization and how these result in different

flavors of image sensors with specific characteristics. Previous technological choices which the organization made result into a path dependency that makes it hard to shift to other concepts.

The organization needs several years to develop these options when it chooses a

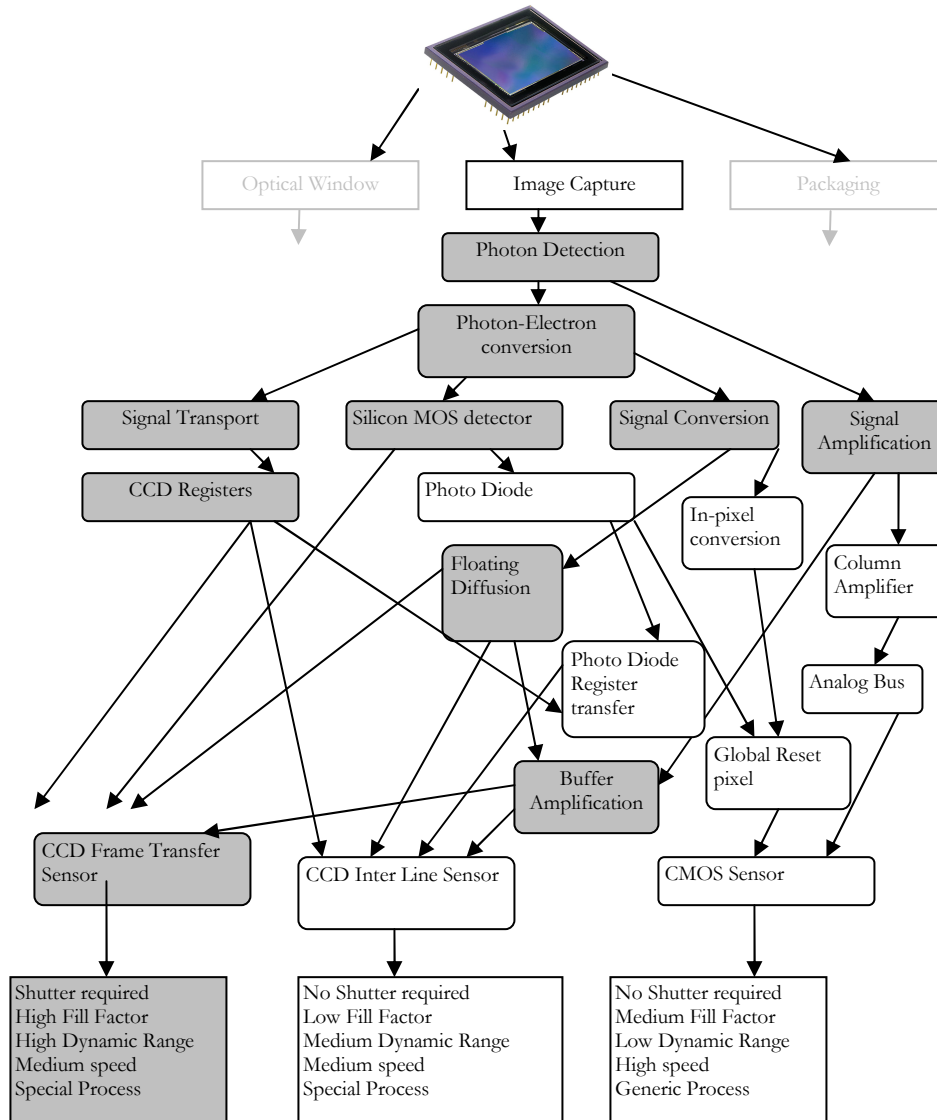


Figure 3.5: A taxonomic scheme of some of the technology options of a Solid State image sensor. The technology options pre-define the product concept and therewith the performance of the product.

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different technological paradigm. It is not only the technology itself which needs to happen, but the organization also needs to learn about the new technological option and gather knowledge to apply it successfully into a product. As the organization develops a routine to deal with the current technological options and gather specific knowledge, an organizational change is required to accommodate a new technological option. The required change is no different from other organizational change processes and will meet resistance and counter forces.

Also psychological factors can play a role in preventing organizations to take a side step, for example if the organization tried to develop a particular technological option before and failed, it will represent subjective evidence that attempts to leave the path are too risky and too costly. This path dependency provides a somewhat different perspective on innovation; it suggests that incremental developments represent incremental innovation along an existing path that has been created by past decisions.

It also suggested that organizations with a rich technology portfolio can push these innovations along a broader path and/or different parallel paths, and finally that more radical innovations are created by developing new technology options that allow new paths. It should be noted that neither incremental nor radical innovations within an organization are necessarily experienced as incremental or radical innovation by its environment.

3.3 Technology Trajectories and Path Dependencies

Dosi and others considered the technology trajectories on a macroscopic scale to give an explanation to large collective technology developments such as in the IC industry [Dosi 1982]. Looking at the IC industry from a considerable distance, it shows indeed that the industry follows a kind of predefined roadmap, giving the technology development a certain direction. The so-called Moore's law gives a prediction of how the IC chips develop in terms of feature size, capacity and other parameters. However, closer examination shows that this major technology trajectory consists of many smaller trajectories and that organizations use slightly different technologies resulting in similar device achievements, but still compliant to Moore's law. Looking at the enabling technologies like IC processing technologies, one will not find a smooth trajectory.

On the contrary, Moore's law which is considered to represent the technology trajectory for the device requires very radical technological changes in the processing technology to make it happen. For example the lithographic technology that is required to project features with a very high resolution on the silicon wafer, hits the boundaries of physics; optical projection will be insufficient in the near future and an alternative technology is required. This is a radical change and manufacturers of the lithographic equipment need to leave the 'optical' technology paradigm.

From the observations in Section 3.2 it has been concluded that an organization follows technology trajectories. These organizational trajectories are sub-branches of larger macroscopic technology trajectories, but are nevertheless discriminating enough to provide a competitive advantage for one firm towards another. The organizational technology trajectory is illustrated by an example based on the earlier used Digital Still Camera (DSC). An important performance parameter of the Digital camera is the ISO-speed¹⁰. The ISO-speed is a measure for the ability of the imager to capture an electronic image at low light conditions, but still with acceptable image quality (i.e., low noise). The performance level of the ISO-speed is considered to be a significant factor for the competitive position of a Solid State Imager manufacturer.

In this example, an organization is considered that provides imagers to DSC manufacturers aiming mainly at the professional Studio Camera market. In efforts to provide imagers to the related Single Lens Reflex (SLR) market, the organization analyses the technology portfolio. This intermediate market segment between professional and consumer DSC markets has clearly different requirements than the professional (studio) market. Where high ISO speeds are less of a concern for studio applications because light is sufficiently available, the SLR DSC needs a high ISO speed in order to provide good images under conditions where light is weak and where light cannot be controlled.

In the foregoing years of technological development, the organization did focus on other technological options than the ones that provide a high ISO speed. The organization faces some complex decisions with respect to the strategy to follow. Important is to consider the window of opportunity that the organization has to address this market. If the organization will move along the existing paradigm it may take a long time before the technological options evolve toward the newly required ISO speed values. Actually, the chance that the technology paradigm will lead to an improved ISO functionality in a reasonable time is very low; the past decisions may have ruled out the possibility that the higher ISO speed performance is met.

This is not unexpected as selecting technological options requires a trade-off between several characteristics of the technological options, and if a high ISO speed is not a real issue before, the previous selecting of the technological options was not driven by this characteristic. Again, this shows that there is a relation between the selection of Technological Options and the technology paradigm.

Once an organization selects a technological option to integrate into their products, it forms a framework for further development of that option in an evolutionary way. The knowledge that the organization gains during these developments is centered around

¹⁰ ISO-speed is a characteristic that originates from chemical film. It is related to the speed of the conversion of the photo chemicals while illuminated. Despite the fact that no similar process is present in an image sensor, this metric is an important metric leading for Digital Cameras. It gives an indirect measure how light sensitive the image sensor is. This illustrates that a measure that is relevant for the old technology (film) is imposed on the new technology (image sensor) in order to benchmark the two.

a more realistic definition of 'best' is to take into account the organizations resources and capabilities to accommodate the shift to another technology.

In Figure 3.6 there are two alternative trajectories given; A^B and B^A . The A^B trajectory branched off from the A^A in the past and it is expected that this branch has more common elements and this may be perceived as a lower risk shift. Even if a branch is selected that has a limited potential and lifetime (A^{BB}), it may provide a solution at lower risks and costs. It may imply that the organization has to shift again to a different trajectory A^{BA} in a later stage. Alternatively, the organization can consider a more radical shift. Although this is most likely more risky, considerations like technological potential, diversity and 'newness' would support a shift like this (B^B) and the impact on the organization will be much larger. The current knowledge base in the organization has limited value and a new knowledge base needs to be developed. In some cases the organization has to reconsider their human resources. Most likely different specialists are required and hiring and training programs need to be initiated.

These examples illustrate that the motivation for change is connected to the feasibility of a solution. However, this is not necessarily a deterministic process. In many cases it is unclear what is feasible or not and judgement is based on cognitive perceptions.

It can also be argued that a technological paradigm shift gives even more uncertainty to the organization because the knowledge base around this new trajectory is limited. This uncertainty will hamper the decision process to shift paradigms, or hampers the pace of change in the organization.

3.4 Sources of Technology in Technology Intensive Organizations

An up-to-date technology portfolio gives a Technology Intensive Organization the opportunity to obtain a competitive advantage in the market place. As discussed before, it also determines the variety of applications that can be covered with this portfolio. In order to feed the portfolio with new technologies, TIOs have to invest in the development of technologies to enable the development of innovative and competitive products. It makes sense to consider the scale of the TIO. A large TIO organizes its technology development typically in a different way than a smaller TIO.

3.4.1 Technology development in Large TIOs

A large TIO will have the means to organize the creation of technology centralized by means of an industrial Research and Development Laboratory. Due to the scale of such a laboratory several technological options can be generated and developed in parallel. In general an industrial R&D laboratory takes responsibility for the first two stages of the technology development; the GTO and STO stage. This implies that an organizational boundary exists between the development of technological options and

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the integration of those options into a product development. This requires coordination with respect to the needs of the organization that develop the products for specific markets, often a product division, and the R&D laboratory.

In some cases dedicated programs are initiated and maintained to secure the development of technological options for specific needs of the product division. The programs are formed around certain functionalities that are considered to be important for the product division. For example, the technology option described in Chapter 4, Case B is related to display technologies and did fit in a larger program centered around display functionality.

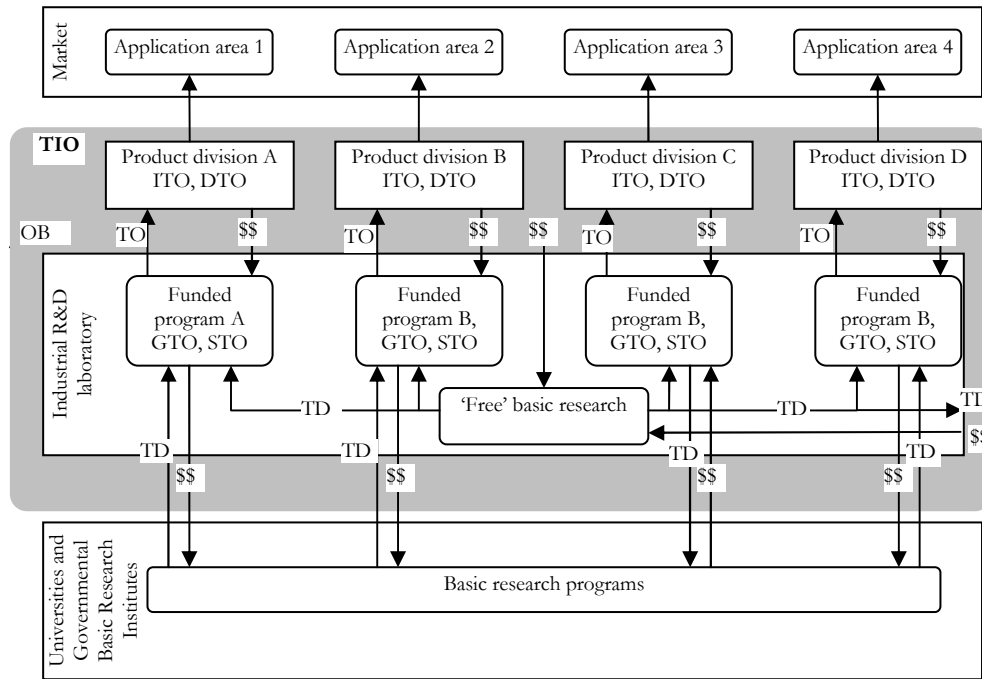


Figure 3.7 An overview of the technology and funding schemes of a large TIO with an Industrial R&D laboratory. The R&D lab provides technological options (TO) up to the STO stage across an Organizational Boundary (OB) to several product divisions. These product divisions provide funding for dedicated programs. 'Free' research results in Technological Discoveries (TD) that can be supplied to the dedicated programs, or can be supplied to e.g. another TIO. In return for funding, Universities and Basic Research Institutes can supply Technological Discoveries to the R&D lab, which support the dedicated programs.

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Although not seen as the primary function of the industrial R&D laboratory, some 'free research' is facilitated. This research is unplanned and is mainly guided by personal ideas of the researchers. This research is often a source of technological discoveries as it represents random search rather than focused search. The balance between free research and planned research is often a point of debate, but the general perception is that some resources should be allocated for this type of research, as the gains of a technological discovery is high.

On the other hand, the R&D lab is dependent on funding from the product divisions, which often demand a more focused approach to direct efforts towards their immediate technology needs. So far the expenditure of free research has been found in the order of 10-15% of the research budget [Nicholson 1998]. Other sources of technological discoveries are universities and governmental funded basic research institutes. These institutes practice basic research and although it is not the primary goal, they often run into new phenomena that have a certain functional value [e.g. Iansiti & West 1999]. It is beneficial for these institutes to obtain interest from industrial R&D laboratories for these technological discoveries, as it will result in additional funding for their basic research programs. In some cases these institutes organize the technology transfer by use of dedicated departments that try to 'sell' these spin-offs from their primary, scientific function.

3.4.2 Technology development in Small and Medium size TIOs

Small and medium sized organizations often do not have the scale to establish a dedicated industrial Research and Development Laboratory. In a sense this complicates the development of technology as it will be practiced interweaved with other processes like Product development, Manufacturing, etc. Cooper notes that the highest risk to a technology program is termination by the management as a result of de-prioritization in short term vs. long term. Where a large TIO with a well funded R&D lab can manage risks by portfolio management; the high reward of a success justifies the higher number of failures, a smaller TIO can only afford a few technology development programs.

This implies that the risks need to be managed in a different way. The typical success rate of a technology development program is in the order of 10-20%, which already illustrates that organizations which can afford only a few programs can easily end up with empty hands. The scale of smaller TIOs requires different ways of accessing technologies. As the possibilities to fund full scale developments are limited, the technological options up to the STO stages are often obtained externally. Midsize TIOs can afford to do strategic acquisitions of smaller TIOs with dedicated technological capabilities. This can be effective as those TIOs are running businesses with proven technologies resulting in relative low financial risk.

By 'cross-pollination', the technologies are exchanged and implemented in the products. Midsize TIOs also have the opportunity to buy licenses to use certain

technologies. In this case a technology transfer takes place where the technology licensor transfers all the related knowledge to the licensee, in order to make the technology operational. Often this requires that the technological options are already integrated in design blocks to provide short time-to-market.

As governments recognize that technologies are important for small and midsize TIOs, government supported industrial R&D institutes are initiated to fulfill the need of technology access and transfer. These institutes are in some cases connected to universities and serve as incubators especially for the small TIOs. These institutes position themselves towards the small and midsize TIOs very similar to the captive industrial R&D laboratories of large TIOs in relation to their product divisions. The main difference is however that the smaller and midsize TIOs have very limited control over what kind of options are developed. It is expected that the government will also use these institutes to steer the development in certain preferred directions. This governmental influence is not necessarily wrong, but it may contribute to the gap between what the Small and midsize TIOs are looking from a market perspective and

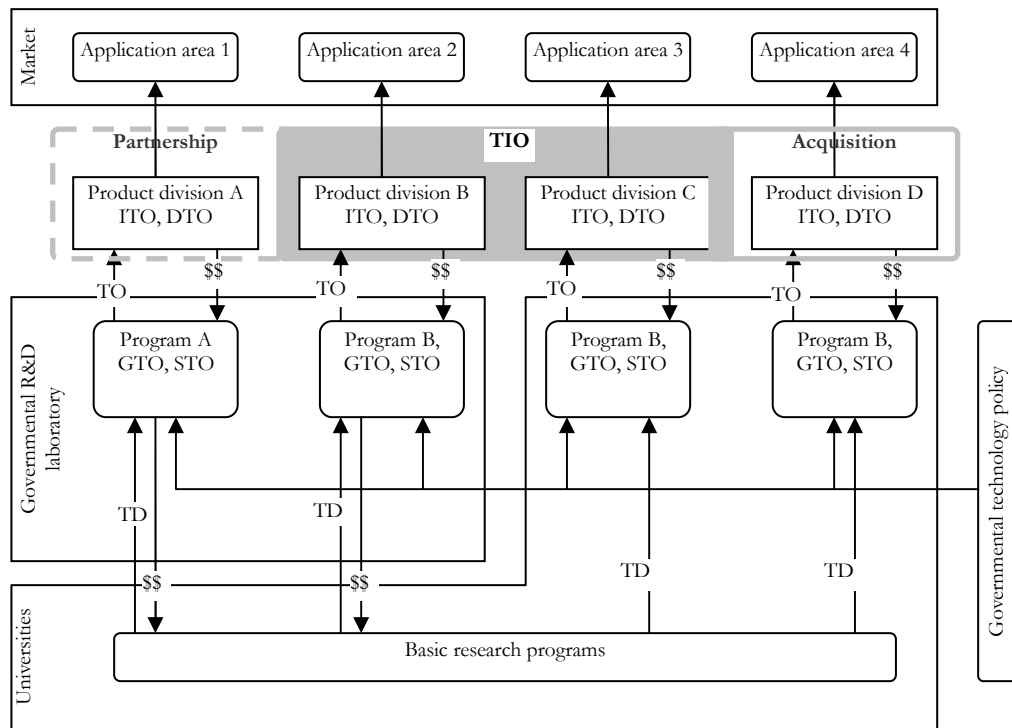


Figure 3.8 An overview of the technology and funding schemes of a small and midsize TIO. A governmental supported R&D laboratory supports the small and midsize TIOs , by supplying Technology options in the GTO and STO stage. Technology Incubator are in some cases connected to an university and support mainly small TIOs. The government tends to define focus points around which the technology development programs are centered.

what is offered by the R&D institutes.

3.5 Technology development as competitive force

Technology intensive organizations need to compete with new technologies to be sustainable in the longer term. New technologies make a difference in added value of the product and therewith define the competitive potential of the product.

The impact of the technology will differ from product to product, but in general it can be assumed that technology provides added value to the user and will give the product a stronger competitive position. The added value can have many different origins, ranging from cost reduction up to new-to-the-world applications (see Table 3.2).

Type of innovation	Driver	Discriminator	Typical Examples
Process cost	Cost	Price	Petro-chemical industry
Product cost	Cost	Price	Car industry, PC industry
Product performance	Specification	Better performance	PC industry
Product feature	Functionality	More features	Mobile phone, PDAs
Alternative product application	Cost/ Specification/ Functionality	Price/Performance /Features	Micro wave oven, Digital camera
New Application	Latent need	Revolutionary function	Telephone, internet

Table 3.2: Drivers of technological innovation, the added value and typical examples

More often the focus is on the latter - innovation that has large impact on society has a large appeal for TIOs: It is the highest level to achieve with respect to product innovation and it puts the TIO on the world map and in the history books. However it is definitely not necessary to have these revolutionary innovations to be successful. Schilling showed actually that TIOs which can be identified as followers, and not the developers of revolutionary technologies, are very successful as well [Schilling 2008, p.91]. This shows that new technology alone is not enough to be successful and that acquiring technology externally is not necessarily a capitulation regarding market leadership. Other forms of innovations may be less visible for the society and therefore less appealing, however from an economic point of view important for the continuity of the TIO.

A process innovation might be related to pure cost: In general a new process enables lower production costs. The final user will most likely not notice any difference in the end product other than possibly a lower price.

The same is often done on a product level. Combination of functionality by redesigning parts results in lower cost and therewith more competitive power. Incremental innovations in terms of improving product specifications often give rise to

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a sector wide 'roadmap'.¹¹ Developing product features gives added value for the customers by adding more functionality, but it also allows for a wider product diversification that can be marketed.

In case of an alternative product application, a new product is introduced in an already existing application. The product fills-in similar functionality however based on a different technology. Consequently the new product has to be competitive with alternative products based on traditional concepts.

A new product application makes things possible that were not possible before. This is revolutionary for society. Initially, the product will have no competition because it is one of a kind.

It is probably true that innovations that really bring something new to society will be the most profitable. The number of 'hits' is however rather limited. Therefore it is unrealistic to focus on these unique and rare opportunities only. Still, the 'ordinary' innovations are still very difficult to achieve, because new technologies will be required, which ask for long term strategic planning and investments.

3.6 The strategic dimension of technology

The decision of acquiring new technology for a Technology Intensive Organization has large strategic implications. Applying the criteria from Mintzberg, leads to the conclusion that the choice to develop new technology needs to be qualified as a strategic decision [Mintzberg 1978]. The amount of resources and effort which are generally needed to develop a new technology alone might be enough to conclude it exceeds the scope of daily operational decisions. Even if the technology is acquired, the required effort is considerable as a new knowledge base needs to be developed. The strategic decision to obtain access to a new technology, takes place after a process of reorientation. This reorientation process concerns acquiring knowledge about the many consequences for the organization and about the new environment. This process can be described in several steps that take place in a typical decision process, related to implementing a new technology.

- Motivation for technological change: It can be assumed that there are always one or more reasons to reconsider the TIO's course. This reason can be either positive or negative. The environment is changing constantly, which gives rise to threats and opportunities. Although it is tempting to think that a well managed organization will react on both the threats and the opportunities, it is more likely that the opportunities will be addressed with less of a 'sense of urgency' as compared to a threat. Changing the course of the organization requires moving outside the comfort zone and can be seen as an obstruction to

¹¹ For example, mobile phone imagers have different standardized formats: QGA, VGA, SVGA, etc

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running operations. Consequently it is assumed that a motivation for a radical change is mainly attached to a necessity like an external threat.

- Orientation on the outside world: As the motivation for change comes mainly from the environment, a constant orientation on the outside world is required. However, after identifying a threat or opportunity and there is a certain sense of urgency, the organization will orient itself on the outside world. This reorientation is very relevant as a technological change in the organization and implies that the existing knowledge of the environment becomes less relevant or even obsolete. During the reorientation, an inventory is made of the relevant (and sometimes irrelevant) factors and developments that are related to the identity of the firm (or the new identity of the firm). From this analysis it will be clarified how the landscape of options will look.
- Mission formulation: A technological change can have consequences for the mission of the organization. Reviewing the mission by a reorientation of the organization's existential questions required for consistent goal setting and strategy development [e.g., Weggeman 1995] further in the change process. The existential questions should be answered in the context of the new environment of the organization.
- Internal reflection: A Strength/Weakness/Opportunities/Threats (SWOT) analysis will refer to both the environment and anticipated mission. The SWOT analysis can result in an extensive amount of effort. Particularly the current technologies and capabilities should be inventoried and benchmarked on the intrinsic performance. Finding proper benchmark data is difficult and time consuming. A lot of information should be gathered, structured, filtered and analyzed.
- Defining the goals of the firm: Given the mission and the strength and weaknesses, all in relation to the dynamic environment the organization, goals will be defined not only to emphasize the strengths and to cancel weaknesses of the organization but moreover will give the organization access to the new technology.
- Inventory of the strategic options: After setting the goals, the strategic options can be identified. The strategic option should reflect which routes the organization can follow to reach its goals: A 'map' of potential routes towards the desired new technology is produced.
- Exploring the strategic options: The map of all the available options is explored and analyzed in terms of advantages, disadvantages and the risks associated with the available option.

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- Strategy Development: Resulting from the analysis a prevailing strategy will emerge. In summary this strategy:
 - o gives meaning to the initial motivation for technological change
 - o coincides with the (new) knowledge about the environment
 - o reflects the mission of the organization
 - o reaches the new goals
 - o pronounces the strengths
 - o deals with the weaknesses
 - o gives the best effect given the risks perception of the organization.
- Commitment: In the final stage there should be a widely carried commitment in the organization about the strategy. All the organizational members that are involved in the realization of the new strategy should have buy-in.

The impact of a technology choice on the organization's performance is considered to be significant. Either developing technology or buying technology are long term investments with relatively long return on investments (>5 years). This itself will induce uncertainty, which will play a prominent role in the decision process. The uncertainty associated with the strategic decision will lead to a path dependency, as it gives rise to opposite forces within the organization. This will be discussed in the next sections.

3.7 Technology, uncertainty and risk perception

Although the product development of a product itself is already difficult and uncertain enough, securing a relevant technology portfolio is even more difficult and uncertain. In general, organizations have trouble dividing their resources between activities for developing new technologies to be incorporated in future new products (R) and for the development of near term new products based on the current technologies (D). This dilemma within R&D organizations is mainly based on the fact that working on D (new products) provides more security in the short term than working on R (new technology). The main reason for this is that a positive outcome for technology development is low (10-20%) and is a long process. Product development is less uncertain and allows for better (financial) planning. This also reflects in the priorities that are set by the organization; the projects that contribute to the financial results in the shorter term prevail over projects that serve the long term financial needs. It is however important that an organization maintains a certain balance between the short and long term perspective.

The wrong balance; only focusing on the short term perspectives, will erode the organization's technological capabilities and at a certain moment the firm finds itself in an uphill battle to compete with products that are based on an out-dated technology base. This itself indicates that the allocation of resources for technology development should be supported by a strategic decision and a strong preservation of this decision

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by the R&D management. A loosely managed technology development scheme often results in organizations facing a crisis situation, where a new technological option needs to be found in the short term, in order to feed the next product development.

It is interesting to focus on the phase before a certain strategic decision is made with respect to the development of technology. An organization that operates in equilibrium and where consequently change is accommodated in an evolutionary manner will take decision in a different manner than an organization in crisis. For any strategic deliberation for any decisions to be made in equilibrium allows for minimum risk, several risks will be identified and weighted based on old (experience) and some new knowledge.

In this 'landscape' of perceived risks, the paradigms are formed by 'paths' of minimal risk. In the metaphor of a landscape with paths, the high grounds represent high risk while a path that follows the minimal inclination represents the lowest risk. An organization in equilibrium can progress along the path of minimal risk and basically there is no short term consideration to look for a higher risk path. This behavior implies that an organization that can operate in equilibrium is allowed to progress incrementally and take up the technology development challenges step by step. Besides the low risk, following this path allows for better planning, as there is less uncertainty of the challenges ahead. It also allows the organization to organize themselves more optimally for the upcoming challenges, by building up specifically relevant knowledge and systems.

It can be said that this forms an ideal mode of operation and, if an organization can permit itself to operate in this fashion; there are no short term incentives to act differently. The question now is when can an organization permit itself to operate in the low-risk mode? There are several mechanisms for an organization to leave the low risk technology path. The preferred mechanism is to leave the path by forward planning; in this case the organization identifies early when the path needs to be abandoned and identifies alternative paths and starts to obtain knowledge about the new technologies early on. The advantage of this approach is that there is more time to de-risk the paradigm shift by anticipation on the required changes in the organization and identify the gaps in knowledge. The downside of this approach is that the organization needs to have excellent predictive qualities to make the right choices upfront.

Although this approach allows for a 'gradual' revolution, where the organization can stay out of the crisis-zone, the risk of investing in the wrong technology is higher because of the early decisions that are taken without considering more recent developments. A technology path that looked very attractive five years ago may become irrelevant by new developments. This shows that there is also an incentive to postpone critical decisions.

Another mechanism is that the organization is forced to leave the technology path. The 'comfort' of the low risk development may jeopardize the ability to foresee upcoming

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dead ends. In the extreme, this leads to a scenario where the organization finds itself in a crisis situation; the next generation product cannot meet the market needs and expectations with the current technology, which directly impact the short term financial position.

In this mode, the organization is not only forced to take higher risks by allowing less time to build up enough knowledge to support a 'good' decision, but also loses time by weathering the storm of the upcoming weakened financial position. The combination of the two jeopardize the continuity of the organization and the paradox is that by staying too long on the low risk path, the risks will be higher when a paradigm shift is unavoidable. On a side note, the metaphor of 'landscapes' and 'paths' can also be applied to effort: reaching the high grounds costs additional effort compared to following the path of minimal inclinations.

Ideally, an organization stays long enough in an equilibrium mode, and schedules a technology shift early enough to feed the product development process in a timely manner with new functionality, though late enough to oversee the most relevant decision parameters. Some times a side path can result in extending the lifetime of a technology. It can be argued that taking a side path has less impact on the organization than jumping to a distant path. Qualitatively, this seems plausible because at a junction of two paths the landscape is the same while jumping to a new path gives a different landscape than before.

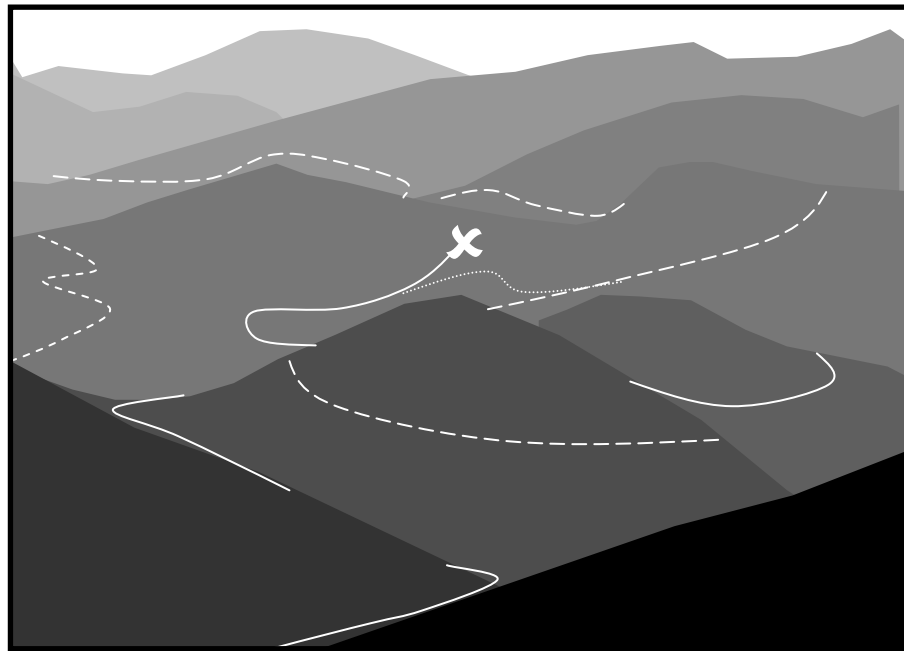


Figure 3.9: The landscape of paradigms; the tendency to innovate but minimize the risk and effort, result in following the valleys and avoiding the high grounds (solid line). A firm roadblock (cross) results in shifting paradigms (transition from solid line to dashed line).

Collective Frame of Reference in Technology Developments

Chapter 4: Initial Field Studies

“One day, while we were exposing Yttrium Hydride to Hydrogen in the laboratory, the sample just disappeared ...”¹²

Chapter 4: Initial Field Studies: The emerging concept of Collective Frame of Reference

This study started without much structure; there was no specific problem description, no research proposal. Only a rough idea about the field of research: innovation studies, and a personally motivated researcher, who wanted to understand how technology development could and should be managed. This lack of a structured research plan did complicate the study in the initial stages. An additional complication was that there was not too much structure in the literature either and the number of publications about technology development is limited. Following Eisenhardt’s paper on building theories from case study research [Eisenhardt 1995], one of the tools is to apply an ‘unguided’ observation of a process, with the purpose to find a particular phenomenon that provides explanatory value for the subject of study.

In order to define the study more specifically, two initial case studies have been executed to find a sensitizing concept in the spirit of the Grounded theory of Glaser and Strauss [Glaser & Strauss 1967]. The case study observations were registered and later analysed with display methods as described by Miles and Huberman (see e.g. Appendix C) [Miles & Hubermann 1994]. The case studies were executed in different Technology Intensive Organizations and were both situated in a technology development environment. The first case study was situated in a large industrial research organization of a multi-national firm and with about 2000 researchers. The study concerned the development of a new display technology after the coincidental discovery of unknown properties of a material system.

The second case study concerned the development of a technological option in order to add functionality to an existing product, and which did require a new process methodology to realise the option. The diagram below shows the relative position of the two case studies presented in this Chapter on the earlier presented value pyramid (see Figure 4.1). The first study is positioned between scientific discovery and technology development, while the second case study is positioned between technology development and product development.

In the first case study I was directly involved because as a student/researcher I participated in a multi-disciplinary team which was initiated to develop a technology based on scientific discovery. This was a unique opportunity as these events are rather

¹² Prof. Ronald P. Giessen quoted in Science News, March 23, 1996, by Ronald Lipkin

rare - even in a large industrial research lab. It is not a daily practise that a new-to-the-world phenomenon is discovered in the first place, let alone that a research laboratory initiated a project to study the phenomena, and develops technological options to exploit it. Moreover, I considered this an once-in-a-lifetime opportunity to actively take part in the scheme of all these events. The first case study was based on a historical analysis and the data collection is based on my own observations and supported by published documents and papers.

In the second case study the researcher was only indirectly involved - i.e., there was no direct involvement in the project, but the project was executed by colleagues. The data collection is based on interviews with people in several levels of the organization.

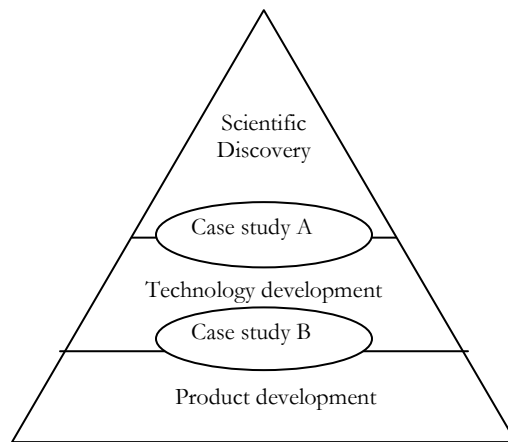


Figure 4.1: The relative position of the case studies in the value pyramid

4.1 Case A: Technology in the making; the switching mirror

The organization in which the first case study is situated is quite unique. The research laboratory is connected to a large multinational firm which has a long history in electrical and electronic products. The research lab has a prominent role in the creation of technological options that are offered to the business units which take care of the product development and the marketing and sales of the products.

4.1.1 Case setting

Although the driving force for the research laboratory is the creation of technological options, the lab is also able to contribute to the scientific community by fundamental scientific exploration of physical phenomena in material systems among others. This is illustrated not only by the large (>1000) of publications in highly rated scientific

Chapter 4: Initial Field Studies

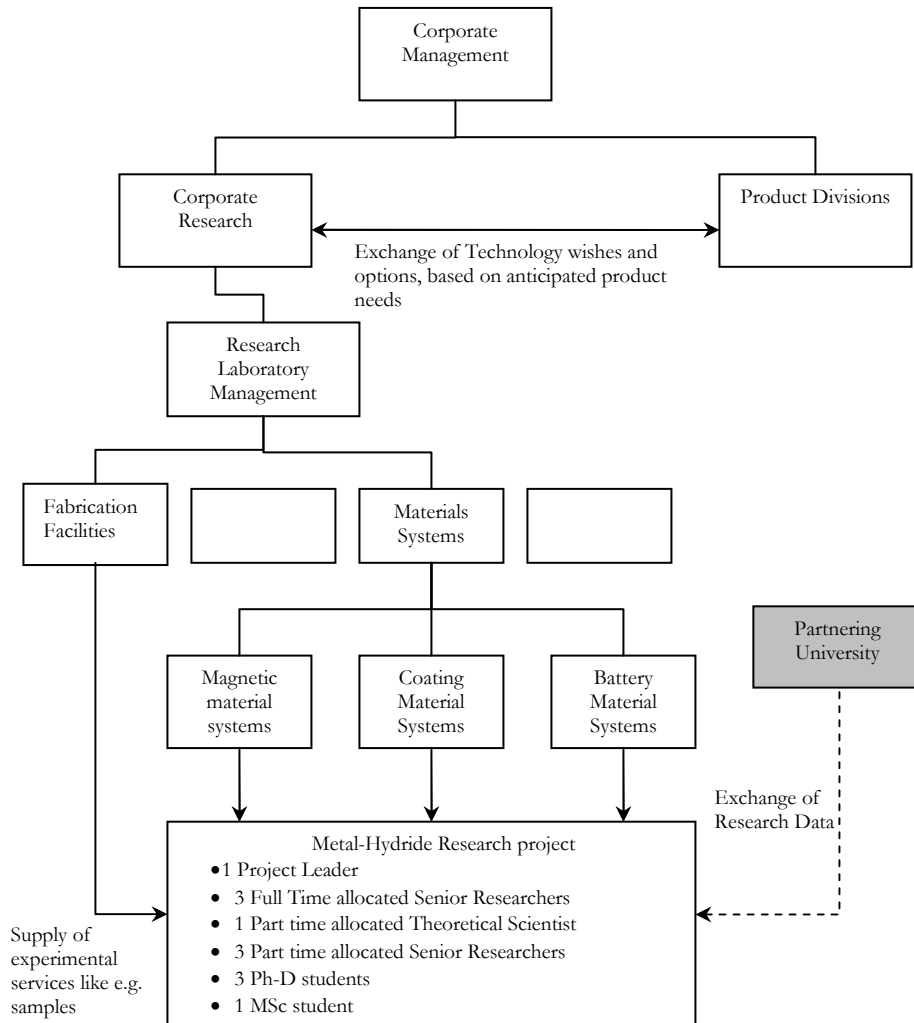


Figure 4.2: The organization structure of Case Study A

journals, but also by the position of the research lab in the international scientific network of universities and research institutes.

Within the organization the technology component is strongly present as illustrated by the immense number (> 130.000) of patents generated by the organization in a national perspective and very impressive in an international context. This observation alone suggests that the researchers working at the research lab have skills which are very similar to scientists with a drive towards scientific understanding on the one hand and on the other hand have skills similar to technology developers with a drive towards practical functionality. The research lab organized their research activities in programs

that were roughly aligned with specific functionalities that could support the activities of the business units.

In some cases these programs were very specific and worked with particular technology roadmaps. For example, some of the research programs that did support the semiconductor business division followed the technology roadmaps like ITRS and SIA, often identified as the well known 'Moore's law'. In other areas it was less defined and could be broadly defined as e.g. programs that define and create new display technologies. From an organizational perspective, multiple groups could work on the same functionality, depending on the expertise of the groups and or group-members. For example a group working on battery solutions, could work on display technologies if the material system that was used to create display functionality, had great similarities with battery technologies. Consequently, a certain project could consist of members of different groups, selected on the specific expertise that was relevant for the phenomena under study.

The research organization also recognized that a certain amount of the time should be spent on so-called 'free' research. This free research was not specifically related to a research program but was purely based on the personal interest of the researchers who had an idea and/or a personal motivation to search for a solution to a not generally defined problem. In the history of the research lab there are several examples of individual researchers pursuing their own ideas that later formed the basis for multi-million businesses. To accommodate the free research the lab had an informal arrangement which was known as 'Friday afternoon' experiments, basically allowing the researchers to spend a few hours to pursue their own ideas. The big challenge was without any doubt, persuading the service department to provide samples and equipment for these 'Friday afternoon' experiments, which were by definition not defined and budgeted. The tension between planned and free research gave rise to ongoing debates about how to organize and manage new technologies.

On the one hand the researcher argued that providing means to a group of developers should be enough to create new technological option while, on the other hand, the business divisions were asked to contribute to the funding of the research lab and basically wanted to have 'useful' technologies for their 'buck'. It also lead to a kind of push versus pull debate, where the business divisions asked for technological solutions that could satisfy a functional need based on certain market demands (pull), rather than for solutions that should be imposed to the market and create a need or appealed to a unknown 'latent' need (push).

Although in general it was recognized that revolutionary technologies seldom came forward from market demands, it was not part of the business model of a business division to fund unplanned research. All these forces within this research organization were actually the direct reason for this study and to study the driving forces behind technological development, this organization seems to be particularly suitable for positioning an exploratory case study.

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The organization structure is given in the situation diagram (Figure 4.2). The firm structure was aligned under the corporate office. The corporate management directed many Business Divisions and the Corporate Research organization. This organization coordinated several research Laboratories, located in several countries. The largest Research Lab was structured along research programs. The research program was headed by research directors that were part of the Research Lab Management.

Every Program had several research groups, headed by a group leader. Within the group, research projects were defined and headed by an appointed project leader. The HR policy was based on a rotation model. In general, PhD or MSc students were hired after graduation and spent five years at the research lab. After those five years they were motivated to leave the lab and continue their careers at the business units of the firm.

For some researchers there was a possibility to continue their career at the research lab and become a senior researcher with the prospect to become a research fellow. In general these people had an exceptional publication and IP record. The core team consisted of four researchers. The team leader had a physics background and was

Dialogue box 4.1: Backgrounds of the discovery of the unknown properties metal Hydrides.

Researchers at a university were studying the Yttrium Hydrogen system under extreme conditions. This research was motivated by the quest for superconductivity at room temperature in the early 90s. One of the theoretical predictions was that metallic Hydrogen could be a super conductor at 200-250 K. A technical complication was that the creation of metallic Hydrogen requires extreme pressures. Therefore an alternative approach was chosen that would require lower pressures by allowing Hydrogen to dissolve in another material first and then pressure this material so that the Hydrogen atoms could form a metallic bond. The expectation would be that this material would be super conducting at high temperatures as well. For this material, the metal Yttrium was chosen as it is capable of taking up three Hydrogen atoms per Yttrium atom. Metal-Hydrides like Yttrium-Hydrides were known for many years but as Yttrium is very reactive with oxygen forming Yttrium oxides, maintaining pure Yttrium in normal ambient conditions was impossible. Therefore Yttrium was not a practical metal and although the Hydrogen storage capabilities were known, there was apparently not much interest before to explore properties of the system in more detail. The advances in thin film techniques allowed the application of a thin layer on a diamond structure that was part of a diamond-anvil –cell that would be used to apply pressure to the layer. The transparent diamond allowed the researchers to observe the switching of the thin film on a transparent substrate.

known for making progress in technology development projects in a short time. This meant that he was attached to a program for a relative short time (< two years).

In the study described here, the team leader was involved in the initial stages of the program. In other programs he became involved at much later stages. The first team member was a very talented researcher with a chemical background, destined for a long career at the research laboratory. The second team member was a very experienced researcher with a 30+ year track record at the research laboratory. His background was physics. The third team member was also destined to a long career at the laboratory and had profound experience in the field of electrolytic chemistry.

The team was further supported by a theoretical physicist, executing computational analysis of the material system and several senior scientists, who were involved in relevant fields, like thin film deposition and treatments. Furthermore three PhD students and one MSc student were involved in the program. The project was supported by various service departments, offering a supply of thin film samples, experimental equipment and other supplies.

4.1.2 Observations

It makes sense to distinguish three different phases in this case study; the discovery, where a new phenomenon is observed, the basic research phase, whereby fundamental research an attempt is made to understand the phenomenon, and the technology development phase where a device is created with a functionality related to the phenomenon. This does not necessarily describe the cycle of every technology but one can say that it describes the process where technology development originates from a scientific discovery.

The Discovery

In the mid 1990s, researchers at a university discovered by coincidence that the optical properties of a particular, so called 'rare earth'-metal Yttrium changed when exposed to Hydrogen gas. The metal was able to switch between a transparent state and a non-transparent reflective state (see Figure 4.3). This reversible behavior was an extraordinary phenomenon and unknown to mankind.

These transition properties were not understood and so far optical transitions in metals were basically unknown. In general the optical properties of metals can be described by very simple models like the Drude model, describing a reflective behavior like what is considered to be typical for metals [Wooten 1971, Draijer 1997]. Earlier research on Yttrium and its Hydrides revealed that Yttrium di-Hydride becomes semi-conducting at certain Hydrogen levels, so the researchers suspected that the behavior was not related to a pure metal state but seemed somehow related to some kind of transition phase from metallic Yttrium-Hydride to an Yttrium di-Hydride compound. This still left open

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the explanation of the optical properties that have been seen in a thin film exposed to Hydrogen gas.

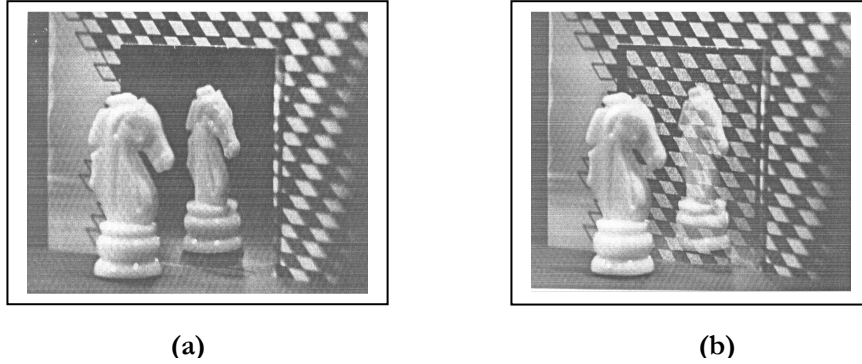


Figure 4.3: (a) The Yttrium in idle stage, where the image of the chess piece is fully reflected in the metallic mirror. (b) After exposing the sample to Hydrogen, the chess piece only partly reflected and the checkerboard background is visible through the sample. After evacuation of the Hydrogen, the state described under (a) can be regained. This is the principle of the optical switch behavior of Yttrium Hydride [Huiberts 1995]

The switching behavior was particular enough to consider a patent application and the university obtained a patent for this gas-induced-switching-material. The research organization of a large firm showed interest in this phenomenon with the intention to use the principle for a new technology. Therefore the firm bought an exclusive license

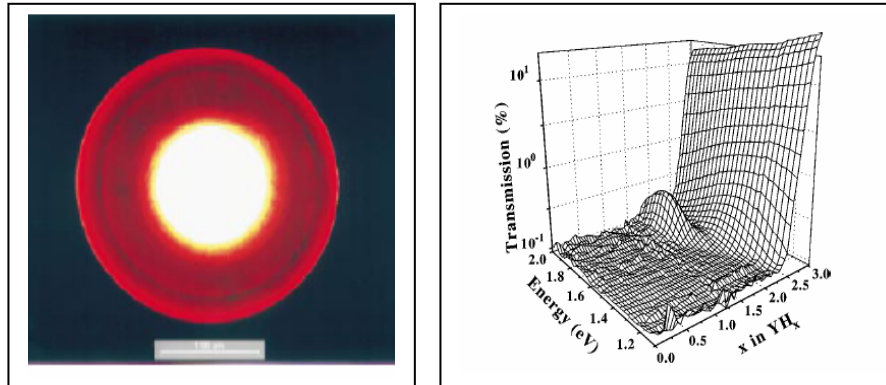


Figure 4.4: **Left:** The optical transition of Yttrium Hydride in a specially prepared sample to study the optical properties. These samples did not have any technological value, but were created to gain understanding of the material system [Broeder 1998]. **Right:** Combined optical and conductivity measurements during the basic research phase contributed to the generation of knowledge about the system as well. [Kremers 1998]

to the patent rights and started to study the application of this effect at its research

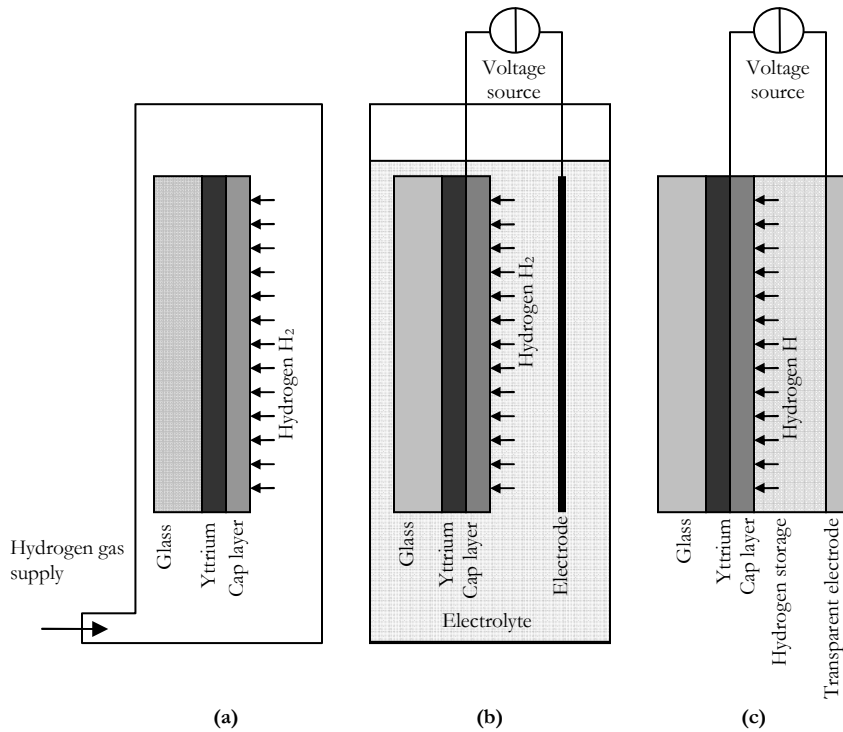


Figure 4.5: The analogue principle of the switching mirror device (a) The original concept based on supplying Hydrogen gas to a closed container. (b) Based on applying a voltage between an electrode and the device, Hydrogen can be supplied to the device. By reversing the voltage the Hydrogen can be pulled out of the device. (c) Analogue to (b) but based on solid state materials, Hydrogen can be supplied from a buffer to the device, again by applying a voltage over the device and an electrode.

laboratory. Also a five year agreement between the university and the research organization was put in place, to cooperate on further research of this phenomenon.

The basic research

The first step was to reproduce the results of the experiments done at the university, so dedicated equipment was designed to realize the gas-induced switching of the metal and a multi-disciplinary team was given the task to study its optical properties (see Figure 4.4) and to further develop this technological option.

Although this material research can be considered as quite fundamental, the possible applications were already reviewed in this stage and even in a prior stage, i.e., before the acquisition of the license.

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The technology

The initial interest of the firm was triggered by the possible application of switching coatings for television screens in order to enhance contrast. However, the gas used to switch the metal was highly flammable and was definitely not suitable to use in a domestic environment. So in order to make the system suitable for application, an alternative for the gas had to be found. This has been addressed in a second implementation of the concept. The basic element Hydrogen, which is responsible for the change in optical properties, needs to be brought near the metal in a different way than by exposing it to Hydrogen gas. An answer was found in battery technology; in general, batteries use an electrolyte to accumulate charge which can be released or stored. This principle was applied to the switching metal. Together with an electrode the metal was submersed in a fluid electrolyte (KOH) that contained the Hydrogen, and by applying a voltage between the electrode and the metal, this Hydrogen was forced into the metal and the switching could be realized. Although the electrolyte-induced switching of the system can be considered safer than the gas-induced one, the KOH electrolyte is an aggressive Alkali, which prevented further application.

So a third implementation of the technology was required. The next logical step was to find a way to store the Hydrogen in a transparent solid state buffer and to bring this into contact with the metal surface and to do the switching by applying a voltage between the buffer and the metal. This solid-state switching device should bring applications within reach and the possibility of using this device as a display element emerged. The researchers succeeded in taking this final step as well: a prototype of a solid-state switching device was produced and even an array of addressable switching elements, so de facto a display was realized. See Figure 4.5.

Technically this project was very successful; the researchers were able to bring this experimentally observed phenomenon to a real application within four years. However, it was decided to halt further technological development. This decision was made because alternative display technologies had become available in the meantime; these were already at a mass production process level. A switching metal display would not give enough added functionality to justify further development.

4.1.3 Longitudinal time line case study A

The time line of case study A shows the relatively short time in which the discovery took place, where basic research was done to gain understanding, a technology was developed and finally where the technology was left on the shelf.

1995

- Start experiments on superconductivity of metallic Hydrogen in Yttrium and Lanthanum at the university.

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- First observations of unexplained optical behaviour of the metal during exposure to Hydrogen [Huiberts, 1995]
- First generation of switching mirror developed YH_x [Huiberts, 1995]
- 1996**
 - First publication of the phenomenon [Huiberts, 1996]
 - Filing of the patent application
 - Agreement between university and research lab on licensing and cooperation.
 - Initiation of research program at the research lab
- 1997**
 - Research towards electrical, optical properties and phase transitions in thin films [Broeder, Duine, Kremer, Draijer, etc]
 - Results on other Rare Earth metal Hydride systems. [e.g. Ouwerkerk 1998]
 - Second generation switching mirror $GdMgH_x$ developed [Sluis 1997]
 - Established optical transition in electrolytic fluid. [Ouwerkerk 1998]
 - Initiation of a theoretical program on calculation of Joint Density of States
- 1998**
 - Establishing optical transitions in a solid state device [Sluis 1998]
 - Creation of a simple display device
 - Initiation of a large program to create larger scale display (electronic book)
- 1999**
 - Termination of the program after feasibility study

4.1.4 Analysis Case study A

Based on the distinction between the discovery, the basic research, and the technology development, the analysis is structured in the same fashion.

The discovery

The discovery of the optical switching properties of Yttrium-Hydrides was based on coincidence; the researchers did not intend to create an optical switch based on Yttrium, but strived to achieve another goal. The researchers were searching for a method to obtaining super conductivity in metallic Hydrogen and decided to use Yttrium as Hydrogen containing medium. Although this was an unplanned, it is intriguing to understand the circumstances under which the discovery occurred. One of the researchers involved in the Switching mirror discovery, professor Giessen, had the following comment: "This switchable mirror is a good example of an inadvertent spin-off from basic research", [...] "We set out to do fundamental science and stumbled into this discovery, which may have great technical relevance." Sometimes, to discover something really new, [...] you just have to play around." [Lipkin 1996].

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This suggests that ‘just doing science’ is the main factor that can influence the discovery of new phenomena. It assumes that there must be a statistical relationship between the number of new and original experiments and the number of surprises that occur in the form of discoveries. This seems to have been the case with the Yttrium experiments. The university reasoned that the creation of metallic Hydrogen was very difficult and decided to take a new route in an attempt to create a similar condition in an indirect way. This led to a new and original experiment that in the end led towards a discovery.

In conclusion, discoveries, defined as finding phenomena that are truly unknown to man are rare, but have a higher chance occurring there where creative science is practiced.

The basic research

The basic research that followed on the discovery was motivated by a need to obtain a better understanding of the phenomena. Although the goal was the same, the background of the motivation was different for the team working at the university and the team at the research lab. The university team was looking essentially for a ‘value free’ understanding of the phenomena and mainly interested in publishing the findings, while the group at the research lab was striving to obtain a better understanding in order to improve the properties. Despite these differences the cooperation was working very well in terms of exchange of ideas, although one could say that there was a kind of ‘healthy’ competition, where the two groups were stimulated to deliver results before the other. Fundamentally this also proved that the research lab and university were equals in this phase of research and the involvement of theoretical resources were not limited to the university only.

In conclusion, the main observation here is that there may be a difference in degree of “value-free”-ness, which may be reflected in the motivation to contribute to a fundamental understanding, but that despite these differences, the methods, techniques and problem solving skills are basically the same or very similar. This is very much in agreement with the notions of Popper, Polanyi and Simon that the problem solving routines in science are not particular and different from other activities (like industrial research).

The Technology

Aside from the basic research, which was required to obtain a better understanding of the optical properties, activities took place to develop a technological option. The group at the research laboratory was working on these activities simultaneously, and although some members were more focused on the creation of a device than others, there was not a clear distinction in activities.

During the quest to come to a device a focused sequence of problem solving cycles were executed. The actions of the researchers were guided by the principle of analogy in more than one occasion (Klahr and Simon, 1999, p533). For example, the following reasoning was followed: the concept works in a gaseous system, where Hydrogen is supplied to the device in the gas phase to try to achieve the supply of Hydrogen by applying a voltage difference between the device and an electrode in fluid electrolyte (analogue to a battery). The next step was trying to achieve an analogue concept within the solid-state system components (see Figure 4.4).

Another observation noted was related to the search for materials with similar properties. The apparently very simple approach of looking at analogue materials in the periodic table of elements was very effective. The team ordered samples of several other Rare Earth¹³ materials and found better candidates than Yttrium. For example Samarium [Ouwerkerk 1998] and Gadolinium [Sluis 1998] showed better switching characteristics.

These interconnected steps were all aimed at realizing a fairly specific solution. One could say that the researchers referred in their actions collectively to a certain ideal. This ideal is not necessarily made explicit in terms of goals and methods to follow. However, it was clear that the researchers had a common basis with respect to the goals that needed to be achieved.

The interesting point is that the researchers in the team came from different groups and had different backgrounds. Some worked on electro-chemical processes, others had a solid-state background, and, although the research methodologies seem to be very similar, the experimental approaches of the individual researchers were quite different. This resulted in progress in the different aspects of the phenomenon. Intense exchange of information and knowledge made that the ideal to be pursued was shared, focusing actions towards the right direction. In this the team leader played an important role by managing this focus through the facilitation of intensive knowledge and information exchange. Almost on a daily basis results were shared and new theoretical insights were displayed and explained. This brought the team members on par with respect to the latest facts and they were able to consider the consequences of these facts for their own research.

Although the link to an application was probably already laid in the license acquisition period, it did not play a direct role in the realization of the solid-state analogue, other than that highly explosive gas or reactive fluid was a barrier to any application. The strategic decision to acquire the license was based on the potential of the technology to obtain a switching coating with high contrast, but the actual technology development was guided by the analogue principle and was focused on display technology. This

¹³ Although Yttrium is not an element of the Lanthanides, it is considered together with Scandium as a Rare Earth Metal as it is found in the same minerals and share very similar chemical properties. [IUPAC 2005](Nomenclature of Inorganic Chemistry: IUPAC-Recommendations 2005 Cambridge: RSC Publ. Edited by N.G. Connelly and T. Damhus

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explains that first an actual solid-state device was realized and later an addressable pixel device. The building of a prototype display on the basis of the switching metal concept was not a priori initiated by management, but evolved from the focused actions within the development team interacting with other focus groups in the research laboratory.

In conclusion, the main observations are that a multi-disciplinary group of people were able to obtain results in a relatively short timeframe. The focus of the group was not specifically supported by a written or verbal assignment other than the wish to create a device. The researchers were each defining their own experiments and decided independently on their course of action. Still, daily formal and informal group interactions took place which apparently kept the theoretical insights and views on the progress central. The group seemed to follow a strategy of analogy in the quest to find better material systems and to develop a device.

Dialogue box 4.2: Epilogue

After the firm decided to put the project on hold, inevitably the work at the research laboratory stopped. The team members published the latest results and started with new assignments. However, the university kept an interest in switching materials and in 2001 a new class of materials was found by a US university that represents the third generation of switching mirrors. Again, this material had optical properties that were extraordinary and not well understood. Based on these materials the university worked on programs where these coatings were used in combination with solar cells. From the firm's perspective the technology is there, but a specific application is not found so far. This could however change tomorrow.

4.2 Case B: Enabling technology; bulk IR-filtering cover glass

The organization in the second case study is quite different from the organization in case study one. A Product Line group, part of a large multi-national is specialized in professional imaging, and develops and manufactures image sensors based on a Charge Coupled Device (CCD) principle. This group had a long history in developing technologies for these devices and was one of the front runners in development after the invention of the CCD in the late 60s.

4.2.1 Case setting

The organization of the second case study fits into a much larger structure of Business Divisions, Units and Product Lines. The relevant structure is given in Figure 4.6. The activities of the group are focused on the development, design and production of professional image sensors. These sensors are applied in high-end imaging applications such as broadcast cameras, medical X-ray systems and high-end studio Digital Still Cameras (DSCs). The group had a very common line organization where is comprised

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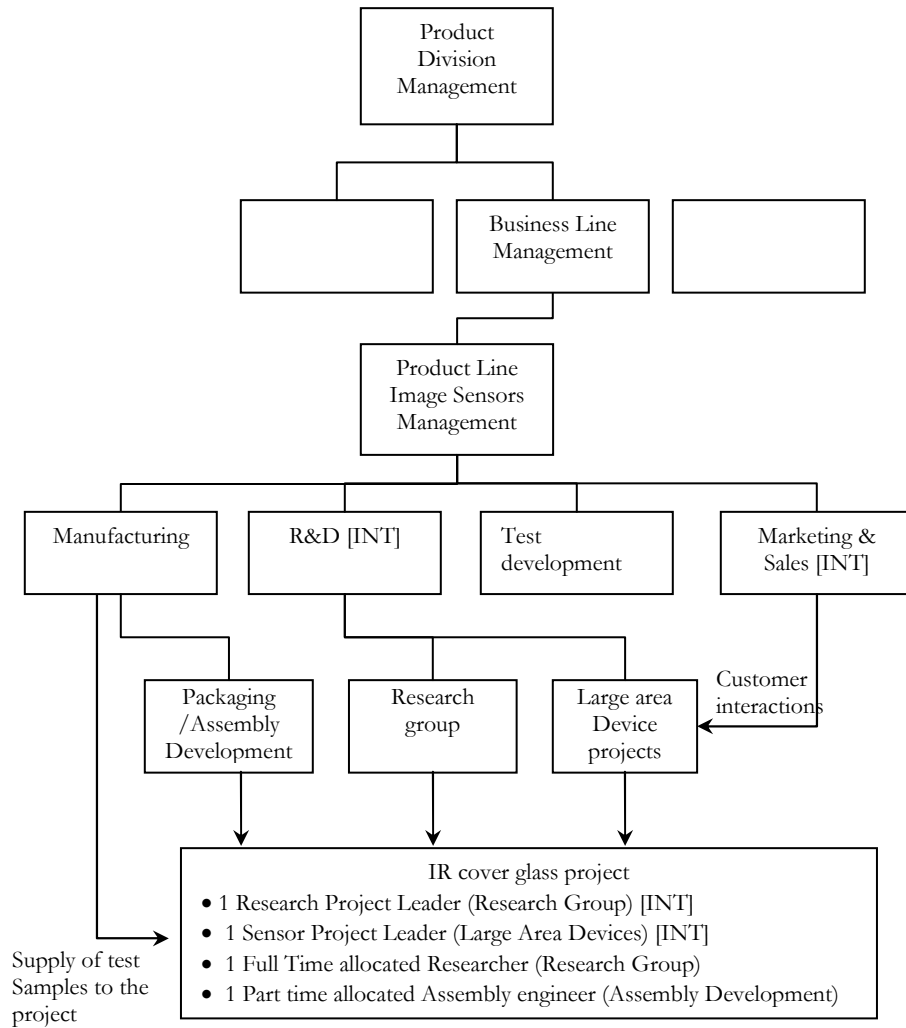


Figure 4.6: The organization structure of Case Study B (INT indicates the interviewees).

of Manufacturing, Research & Development, Marketing & Sales and Test Development representatives in a Management Team headed by a General Manager.

Within the R&D department there is a small research group which focuses on technology development although in general a large amount of available manpower is used to support product development by execution of device simulation projects. This group had a very loosely defined mandate which is more focused on pre-development rather than on technology development. In this sense the developments within the research group have a strong evolutionary character where gradual improvements are done on existing technologies.

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In effect there was no or hardly any time available to work on real new developments. Apart from the research group, a project group was defined which was responsible for the product development of devices which typically have large optical active areas and multi Mega pixel resolutions [Kreider 2002]. This group had some project leaders who often execute the design and who are responsible for all other activities required to make an image sensor product.

The manufacturing group is responsible for the manufacturing operations, the assembly process development and package design. This package is, in general, a ceramic housing in which the Silicon imaging chip is mounted. With a wire bond, connections are made from the leads on the silicon chip to leads in the ceramic package. By internal routing in the package, the image signals are brought to an array of pins that can be connected to, e.g., a camera board. As the device needs to capture light, the package is enclosed by a transparent lid. Often glass with an anti-reflection coating is used for this lid. The cavity is in some cases hermetically closed and filled during the assembly process with an inert gas, e.g., Argon (see Figure 4.7). These hermetically sealed packages are air tight, which basically means that the noble gas will not be exchanged with the ambient air for a long time. The advantage of a hermetic package is that it prevents condensation when the packaged sensor is exposed to low temperatures. Water condensate on the glass lid should be prevented as it will give distorted and foggy images.

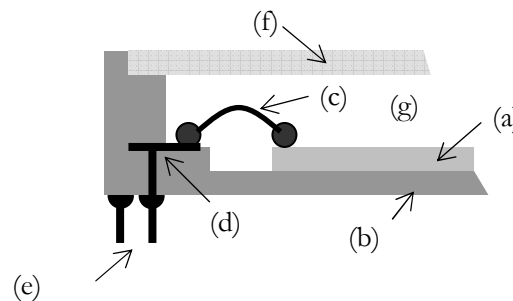


Figure 4.7: Cross-section of a silicon imager (a) in a ceramic Pin Grid Array (PGA) package (b). With wire bonds (c) an electrical connection form the silicon chip to the internal routing of leads. The leads are internally connected to array of pins (e). The package is closed by a window glass (f), resulting in a hermetically sealed cavity (g), containing an inert gas, e.g., Argon

For every new silicon design a dedicated ceramic package is designed. The assembly process takes care of mounting the chip into the ceramic package, makes the wire-bond connections and glues the window glass in an Argon gas environment. In general, the

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packaging development group did focus more on setting up new production lines for a new device without necessarily changing or improving the technology. In actuality there was a preference to keep the assembly process as unified as possible.

Typically, new developments were initiated within the research group in close interaction with the project development groups. Aside from innovations on the actual silicon imaging chip, the group was, to a lesser extent, used to develop innovative packaging technologies. This case study is positioned around such a package innovation. Within the organization there was some debate about where the responsibility should lie for package technology developments.

It was decided that the research group should take the lead in this project and consequently the research project was run by the leader of the research group. The Project Leader from the Large Area devices group was also directly involved to follow the project closely and to provide updates on the project progress of the image sensor development. A Product Manager from the Marketing & Sales group gave customer updates to the Project Leader Large Area devices who brought this input to the research project. A full-time researcher and a part-time assembly engineer were planning and executing all the experiments required making technological progress.

4.2.2 Observations

In interactions with a customer (customer Y), representatives of the image sensor development group decided that a new technological feature should be offered which, in turn, enabled the integration of IR cut-off filter functionality within the image sensor package concept.

As part of a camera system, an IR cut-off filter is applied somewhere in the optical light path through the camera lens towards the sensor. The purpose of this filter is to discard the Near Infra Red (NIR) and Infra Red (IR) components of the optical spectrum falling onto the sensor. The reason for applying this filter is to remove any non-visible image from the scene. Especially the NIR can still be detected by the silicon, but does not provide any 'useful' information for the user of a camera, as the human eye is insensitive to NIR light (see Figure 4.8). Basically, NIR light falling on the image sensor will be seen as 'noise' by the user as the image captured by the image sensor contains information that is not seen by the photographer.

Integration of this filter function into the cover glass has the advantage that the optical design can be made more compact. The development of this technological option was spread over a period of about 10 years and it was mainly customer oriented, i.e., if there was a specific customer question, the development progressed.

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Long before the request of customer Y to consider the IR cut-off filter glass, the group



Figure 4.8: The difference between a normal visible image (a) and the NIR image (b) to which the human eye is insensitive. A silicon image sensor can ‘see’ both images, but in general only the visible is interesting as it resembles what can be observed by the photographer and the NIR image is perceived as ‘noise’ if not removed from the scene. Picture from Zhang et al.[Zhang 2008]

was working on this option, but with limited success. About eight years before, a different customer (customer X) requested this option as a ‘nice-to-have’. At that time, integration of a silicon chip in a camera was relatively new and customer X, who can be characterized as an ‘early adopter’, found out that in order to prevent image distortions, an IR cut-off filter was required. Consequently, the customer X requested to use a bulk filter glass rather than a transparent cover glass. In some initial tests all produced samples failed: the IR filter glass broke during or right after the assembly process due to a mismatch in thermal expansion coefficients between the ceramic housing and the bulk filter glass. The general perception was to discard the option as it was unfeasible and start considering alternative technologies.

One alternative was to use a normal transparent cover glass and apply a special coating on the glass that had similar characteristics as the bulk glass. This coating was based on a stack of layers that allowed for an interference based IR cut-off function. The coating had a pronounced disadvantage due to a radial shading effect (see Figure 4.9), which made this option unsuitable for the intended high-end applications. After these experiments no structural actions have been initiated to develop this technology. However, one researcher kept on looking for a solution over a time span of several years. He was exploring several options; doing small experiments aside from his daily activities.

During this period, a profound disagreement developed between him and the assembly department. The main point of disagreement concerned the possible solutions and restrictions implied by the current assembly process. This difference in opinion resulted in the assembly department initiating some experiments to search for a solution along

the existing assembly process. The experiments of the researcher and the assembly departments were uncoordinated and misaligned.

This period can be characterized as divergent, as expanding search paths were taken and the researcher was not too much bothered to look at concepts much different from the established assembly practice. The work was not specifically supported by the management, it was also not hindered; it was tolerated. This researcher had the belief that it should possible to find conditions to keep the cover glass intact despite the mismatch in thermal expansion coefficients. He also had a strong belief that an organization like the one he was part off should 'see it as an honor' to develop such a technology.

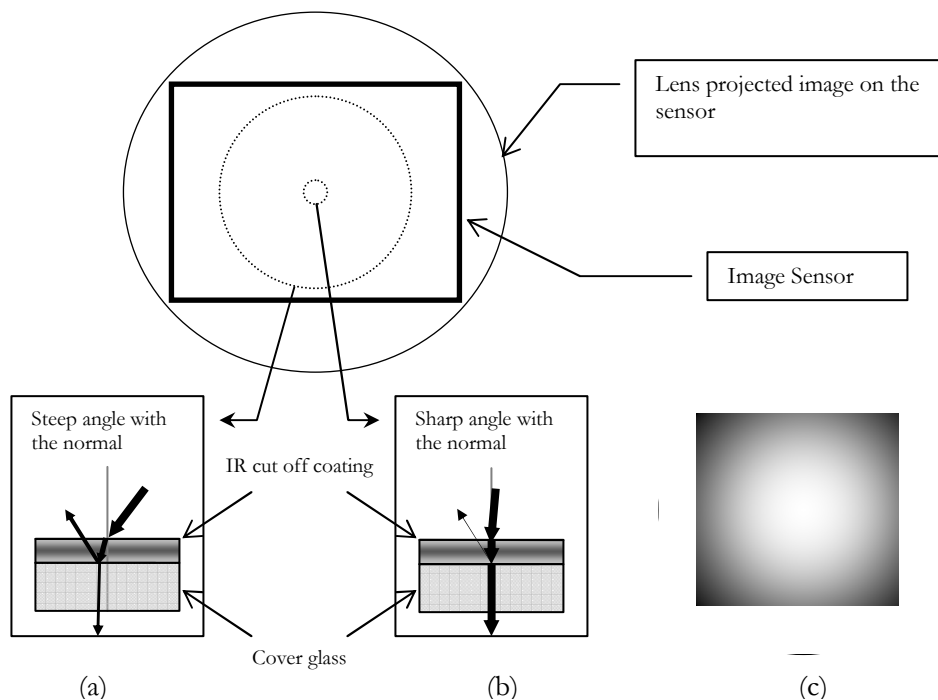


Figure 4.9: Issue with interference coating on a cover glass. The lens projected image on the image sensor has a radial angle dependency; the further from the optical center axis the steeper the angle of incidence. Steeper angles lead to destructive interference (a) reflecting the light at desired wavelengths. At the center of the image the sharp angles (b) allow for a proper IR-cut off functionality and optimal transmission at the desired wavelengths. A schematic representation of resulting image (c) shows a pronounced radial shading effect of the image projected on an image sensor, where the center is bright while the scene becomes darker towards the outside of the scene.

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While making progress slowly, customer Y came along and, rather than having the wish to have an integrated solution with a bulk IR cut-off filter glass, they insisted that the packaged image sensor should have this option and that the package should be more compact. This changed attention of management substantially. Management identified customer Y as a strategic partner and the bulk IR cut-off cover glass was seen as a must to support the significant business. This was also the time that it was being debated as to which department should take the lead in the development of this packaging technology: the Research & Development department or the Manufacturing department. In this phase management took the following decisions:

- The development of this technology development project became a part of the product development project and thus fell under the responsibility of the R&D department.
- The actual technology development was outsourced to an external organization.

The scope of the technology option was defined as a package concept that:

- could be fitted with a bulk IR cut-off Filter cover glass
- was compliant with all the regular Qualification and Reliability requirements
- could be fitted with a hermetic seal
- was compatible with the existing window seal technology as used in the assembly process of that time

At that time both the personally motivated researcher and the assembly department were working on this option in an uncoordinated, unstructured and misaligned way. The solution for the new technology was not in sight. The management decided to invest in an external development rather than initiating a more formal internal technology development program. This was motivated by the assumption that a higher level of knowledge could be found externally.

The management was also uncomfortable with the disagreement between researcher and the assembly department. A significant Non-Recurring Engineering (NRE) fee was paid to the external organization which was known for its expertise in opto-mechanical components. Unfortunately this did not yield a positive result - the external organization was unable to realize a process that could deal with the thermal mismatch between the sensor package and the bulk filter glass. Like the first attempt several years earlier, the tests resulted in a breaking of the glass after thermal testing.

After this failure the management decided to stop the project and explained to the customer that it was not capable of providing the option. From this point on the customer started to experiment themselves as they badly needed this option and the point of no return was past.

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During the period of outsourcing, the failing devices and the management decision to stop further developments, the particular researcher had continued to work on this option, and made some progress. A model was developed, and the results showed that there was a theoretical solution to the problem. After convincing management that this technology option was feasible, limited financial resources were supplied, a more formal project team was formed and the project was tagged as a dedicated technology development project. From that point on the project was converging and several people were involved to continue the experiments, to test the devices and qualify the process. This finally resulted in the IR cut-off cover glass technology. The customer however cancelled the project, not so much because of the IR cut-off cover glass, but for other reasons.

The interviewees gave a consistent view on this case study. During the interviews the following verified and cross checked patterns became visible.

- Management had the impression that the un-planned research was undesirable, and in hindsight action should have been taken to prevent it from happening.
- Management decided to stop the project, but people kept on working on the option.
- The project group found that management was indecisive about the development of the technology options in general, because only after high pressure of a customer decisions were made to develop the technology.
- Management found that the input from marketing was too limited to justify clear technology decisions.
- Within the organization, very different opinions coexisted and, in a particular period, uncoordinated and misaligned actions were taken.
- The project leader indicated that this disagreement led to indecisiveness at the management level.
- The interviewees indicated that the execution of a technology development tasks within the product development phase is undesirable.
- The project group had the impression that management lacked a belief in the organization's own capabilities and knowledge.
- The interviewees found that setting a unified image of the goals was very important. This image was lacking initially and when applied later, it resulted in a successful development.

4.2.3 Longitudinal time line case study B

The time line of case study B shows the relatively short time in which the discovery took place, where basic research was done to gain understanding, a technology was developed, and finally where the technology was left on the shelf.

Chapter 4: Initial Field Studies

1992↓

- Customer X is interested in new sensor product for Digital Still Camera product
- First discussions with customer X about the IR cut-off filter and the option to integrate the filter function in the cover glass.
- First samples of an IR cut-off filter cover glass glued to ceramic package. None of the samples survive the basic packages tests.
- The customer accepts that it cannot be done and the requirement is removed from the specification.
- The firm stops with structural development of the technological option.
- A researcher starts to do some limited experiments to make progress for the integrated IR cut-off filter option.
- The customer loses interest in the sensor product after change of management.
- The sensor development project stops.
- The researcher continues to do some limited experiments. Management tolerates the effort, but assigns no budget and/or formalize a research project.
- The firm talks to several other parties about the sensor and start selling devices in larger numbers

1998↑

1999

- The IR cut-off option is so far never offered and or required.
- The researcher is still doing some experiments under a toleration regime.
- Some positive results are obtained, but the yield is still too low.
- A profound disagreement is developing between the researcher and the assembly department.
- The assembly department is initiating some experiments in order to find a solution in line with the existing assembly practise.
- Customer Y starts to do inquiries about the sensor in a special package, with the IR cut-off filter option.

2000

- Customer Y is becoming a strategic account, due to the high business volume perspective.
- Customer Y is putting filter cover glass as a must have.
- Management decides to outsource the filter cover glass research to an external applied research organization. It is executed as part of the sensor development project.

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- The researcher is still working on this option, but his work is not part of plan research.

2001

- The external development fails and a dedicated project is initiated based on work of the researcher.
- In about 6 months the option is working and qualified.
- Customer Y is cancelling the project, for reasons not related to the sensor package.

2002

- Option is available and on the shelf.

4.2.4 Analysis case study B

Figure 4.10 gives a graphic representation of the main events and activities in the case study. From this case study the following characteristics were deducted.

Bi-Level structure

This case clearly showed the bi-level character of the organization in the perspective of the technology development. The management, provider of resources and responsible for business planning, took decisions from a different perspective than the technology developers. The point here is not about whether decisions were right or wrong, but it is about the perceptions that lead to certain decisions. Evidence was found that these perceptions did differ between the two levels.

Dualism

In the divergent phase, dualism occurred between search actions related to 'open end' searching and 'confined' searching. Forces in the organization liked to limit the solutions by requiring compatibility to an existing practice. This led to disagreement and misaligned and uncoordinated actions.

Non-Conformity

On several occasions, non-conformity was observed, management decisions were not strictly followed, and unplanned actions were conducted. These actions were tolerated, and to a certain extent facilitated, although never formalized.

Divergent-Convergent Phases

The development process has divergent and convergent phases. It was found that during the divergent phases no unified 'image' was present about what the technology should look like. In this phase at least two different 'images' did co-exist. Once a model of a particular concept showed a theoretical solution, a convergent phase occurred that

seemed to be correlated to a unified image. This is quite similar to the notion of centrifugal and centripetal forces for new product development, stating that the organization should accommodate creativity and collectivity in order to realize a radical new product [Sheremata 2000].

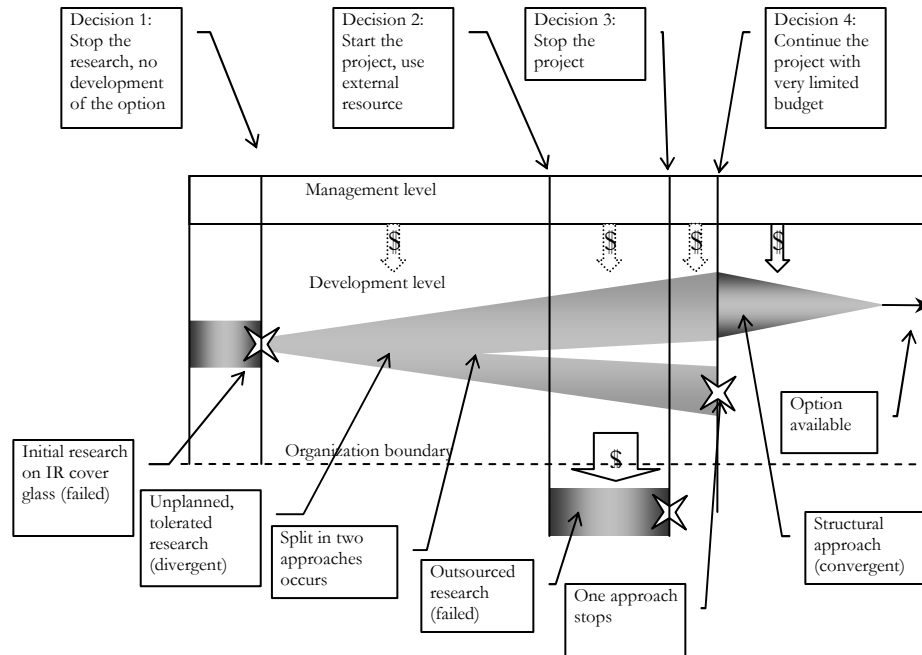


Figure 4.10: A graphic representation of case study B

Personal Beliefs

Personal beliefs, or maybe even passions, played a very important role in this case. The researcher, who carried on despite opposing management decisions and conflicting forces, was motivated by strong personal beliefs. Once the feasibility of the option became clear, and a formalized project group was formed, the actions became planned and focused.

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Chapter 5: CFR Concept

“The first thing to make clear is that scientists, freely making their own choice of problems and pursuing them in the light of their own personal judgment, are in fact co-operating as members of a closely knit organization.”¹⁴

Chapter 5: The Concept of Collective Frame of Reference

Based on the theoretical framework of technology development, established in Chapter 2 and the results from the two initial case studies reported in Chapter 4, the hypothetical concept of ‘Collective Frames of Reference’ or CFR will be formed and described in this Chapter. The purpose of introducing this concept is to support the hypothesis that it has an explanatory value for the course of actions during technology development phases in Technology Intensive Organizations. In later Chapters more specific research towards CFR patterns will be described. The goal of this Chapter is to establish the CFR concept and form initial hypotheses that will be further refined in an additional case study presented in Chapter 6. The concept of CFR will be described on the basis of a number of elements that are derived from the theoretical framework and the initial case studies. From the theoretical framework the following elements were deducted.

- Technological Paradigms: technological development is susceptible to path dependencies; consequently technologies are developed along a path in an evolutionary manner. At some instances development along the path does not provide the required technological functionality the organization envisioned and a crisis emerged. As a result of this crisis, the organization is looking for new technological paradigms that are expected to provide the required functionality. During the crisis (parts of) the organization go through a revolutionary period. These revolutionary periods allows for routine breaking activities and often require organizational changes.
- Problem solving routines: Technology Development consists of problem solving routines, comprising the following phases; problem definition, defining the goal state, selecting the search strategy and applying test routines. The problem solving routines are executed by individuals but is expected that some form of organization is presents where joint progress is made in a certain direction. This direction is expected to be defined by the Technology paradigm.
- Multi level organization: The Technology development process is a multi level process where at least two levels can be distinguished; the management level and the technology development level. Those two levels closely interact during the technology development process. The technology management is

¹⁴ Polanyi, in “The Republic of Science” [Polanyi 1962b]

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allocating the required resources and budgets for the development of a certain technology. In general the boundary conditions for the development will be defined at this level. Certain expectations about what the new technology will contribute to the organization's competitive position will be set and based on these expectations, the resources and budgets are allocated. At the development level, the problem solving routines are executed, often in a dedicated project structure.

The technology developer level can be comprised of a team of representatives from various departments in the organization. For example, a representative of the manufacturing department participates in the technology development in order to solve particular manufacturing issues with the new technology. This also promotes the lateral involvement of the departments that will be affected by the new technology. Within this project structure a group of individuals are executing development tasks mainly in focussed manner.

- Teleological change process: The change process that is related to the technological development has a teleological character, which is mainly driven by the problem solving routines. By setting a global goal state, the group of individuals will set individual goal states that are in line with the overall goal state. This overall goal state serves as a guiding mechanism for the individual activities.
- Internal and External communications: As with other project structures, the internal and external communication plays an important role in technology development projects. The internal communication is mainly focussed on managing the internal processes. The external communications is focussing on information gathering and securing resources and budgets.

From the initial case studies the following elements were observed:

Case A:

- Researchers with different knowledge and methodological backgrounds were using different approaches but still coherently working towards a unified goal. In line with the theoretical framework, the researchers were exploring the solution space by taking different routes, while internal communication allowed for a clear vision of the required goal state.
- The researchers adapted a specific search strategy based on analogy. It is assumed that this helped them to search for similar solutions.

Case B:

- The technology development project consisted of divergent, convergent and dualistic phases.

Chapter 5: CFR Concept

- During these phases individuals exhibited conforming behaviour in convergent phases and non-conforming behaviour in divergent phases, relative to the management perspective.
- Personal beliefs were driving non-conforming behaviour - an individual had the strong personal belief that a particular technology needed to be developed while his organization abandoned the idea, due to feasibility issues.

These theoretical and empirical findings contribute to the concept of Collective Frame of Reference. A schematic representation is given in Figure 5.1 and shows the theoretical and empirical elements that are expected to contribute to the CFR concept.

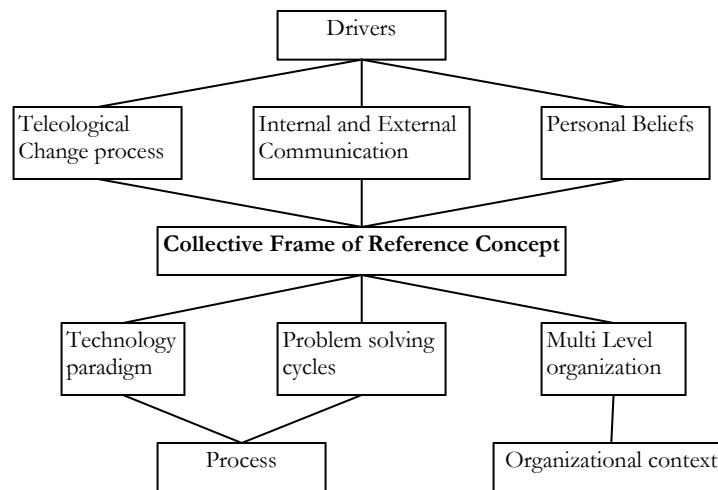


Figure 5.1: The main elements contributing to the Collective Frame of Reference Concept

5.1 Qualitative description of the elements constituting into CFR

Technology development takes place within a distinct organizational structure like a project, often part of a larger organization (e.g., a firm). Dosi assumes that firms as a part of an economical sector follow a technological paradigm and that the technology is developed from a certain knowledge base. This implies that within the organization, the paradigm should be 'felt' and followed. Moreover, it implies that the knowledge base within the firm is related to the paradigm and that the organization has been organised to follow the paradigm. This is reflected in, for example, the development of a specific knowledge and hiring and maintaining certain specialists carrying this specific knowledge. It is assumed that the organizational paradigm is distributed over several sub-divisions of that organization, which follow distinct parts of the overall paradigm. It is expected that the breakdown of those sub-paradigms follow the distributed

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knowledge base of the firm. Conversely, all those partial paradigms, related to the distributed knowledge base, together the overall paradigm of the organization.

Assumption 5.1: A paradigm, followed by an organization, is comprised of partial paradigms followed by the organizational subdivisions within that organization and these partial paradigms breakdown along the distributed knowledge base of the organization.

With the assumption 5.1 is valid, it is implied that, within these organizational subdivisions, not only the (partial) paradigms are followed, but also that paradigm shifts are initiated within the sub-divisions. It is here, where the crisis emerged as the problem, that solving routines are stalling and the goal state seemingly cannot be realized.

In this perspective the goal state is not part of the ruling paradigm. This will not be a clear cut conclusion; the problem solving routines will continue to be deployed before there is a 'certainty' that goal state cannot be reached. Before the belief is settled that the ruling paradigm obstructs the goal state, search strategies will be changed and problems will be redefined. As problem solving is primarily an individual process, the belief that the paradigm shift will be initiated by an individual.

Assumption 5.2: A paradigm shift will be initiated by an individual, concluding that obtaining the goal state in the problem solving routines, are obstructed by the ruling paradigm.

The conclusion that the current paradigm ends will be either accepted or rejected by the group. However, once the group accepts the conclusion it basically acknowledges that a crisis is imminent.

The belief that the paradigm is obstructing the realization of the goal state is not necessarily a 'justified' belief, in terms of an absolute knowledge. It is subjective and can be unjustified or in some cases just plain wrong. Still, it becomes an organizational reality that can have consequences throughout the organization. The impact of the paradigm shift can vary heavily- it can be a localized crisis that hardly propagates beyond the group boundaries and can be solved by a quick fix.

Assumption 5.3: A crisis in a sub-division of the organization will propagate laterally and vertically throughout the organization. Consequently the organization will change from an equilibrium situation to a crisis situation.

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In this case that the paradigm can be changed slightly i.e. just enough to realize the goal state, the crisis is not really a crisis. One could argue that this fits the evolutionary development of the technology along the ruling paradigm where the paradigm is gradually changed to accommodate the realization of the goal state and the organization can accommodate in a relative equilibrium state. In case that the crisis can not be solved easily, the crisis will eventually propagate upwards to the management level as the crisis will affect existing plans, require different resources levels and need special budgets. Aside from this vertical propagation the crisis will also propagate laterally to other subdivisions and the crisis will impact especially the subdivisions that have a (mutual) dependency. In some cases the technology paradigm of one subdivision is heavily dependent on the technology paradigm of the other and consequently a crisis in one subdivision creates a crisis in the other and basically leads to a chain reaction.

Once the crisis situation is acknowledged, the organization will shift from a focus on the paradigm to an unfocussed state which allows for reorientation. The term unfocussed is related to the lack of overall organizing structure during the problem solving routines. The problem solving routines that are deployed while following a paradigm are not fundamentally different from the problem solving routines that need to be deployed to overcome a crisis. Akin to Kuhn's revolutionary science, the solution space is however much more open ended and requires routine breaking and unconventional methods to find a new technology paradigm. The mode of operation relies more on individual efforts and one can argue that the explorative search can benefit from incoherent individual activities alternated with more coherent, joined activities.

The incoherent phases allow entering the new solution space from different angles and with individual approaches. The individual will set the goal states and search strategy of the problem solving cycles in an internally motivated and uncoordinated manner. This motivation can originate from personal beliefs. This mode of operation relies on individual creativity and hardly allows for any task oriented management inputs. Once a hopeful trend is found, it is beneficial to operate jointly in a more coherent way to make progress more focused. Although this mode allows for more task oriented management input, it still is a process that is different from the equilibrium state related to following a paradigm. The notion here is that some coherence exists in terms of the goal state and the search strategy. This mode is still volatile as there is no established paradigm yet.

Assumption 5.4: In search for a new paradigm, progress is made by relying on alternating modes of individual creativity with almost no task oriented management input and a more coherent mode that allows for some task oriented management input.

This pattern of coherent and incoherent activities needs to be carefully managed, as the combination of both modes is important not so much persistently the one or the other. The term “incoherent” does not imply that the activities are incoherent in an absolute manner; instead incoherent refers to the activities within the group where it is assumed that the majority of the group members are coordinating their activities in a coherent fashion.

5.2 Collective Frame of Reference as Shared Unjustified Belief

The concept of Collective Frame of Reference (CFR) is introduced as an acting mechanism for the course of action moving from a coherent mode to an incoherent mode. In this perspective the presence of a CFR allows for a coherent deployment of the problem solving routines, while the absence of a CFR leads to incoherent deployment of the problem solving routines. In the case that a group is following a technology paradigm the CFR is fully present and the individuals have a common understanding of what the goal states should be and have confidence that with a certain search strategy, either personal or common, the goal state can be reached.

At a certain point in time one of the individuals is experiencing difficulties in obtaining the goal state and uncertainty about whether the problem solving routines can be completed is growing. Internal communication within the group is imposing this uncertainty on the group and this is reflected in the deterioration of the CFR.

Akin to Kuhn's notion that paradigms are not shifted after the first anomaly appears but rather after an accumulation of anomalies, the encountered difficulties will not directly lead to a crisis and the group will deploy more effort to find solutions slightly outside the existing paradigm by changing the search strategy and methods. If this additional effort is effective, the CFR will grow again, as the uncertainty that the problem solving routines will lead to realizing the goal states will be reduced.

In the situation that the quick fix is ineffective, the CFR diminishes and a crisis is imminent. In the phase that the CFR is absent, the individual group members will shift to personally motivated problem solving routines. What is important is that in this phase, the internal communication is still sufficient, as it is expected that more effort needs to be done to exchange information between the group members. Once a hopeful trend is found, group members may decide to join forces again to further develop the possible new paradigm. This results in the occurrence of the CFR. The strength of this CFR will be limited though as the certainty of finding a new paradigm is still limited.

The best way to describe the concept of the Collective Frame of Reference is as ‘shared unjustified belief’. Where knowledge is defined as ‘justified belief’, the CFR is a softer version of knowledge and is qualified as ‘unjustified’ since it is subjective based on intuition, relies on past experiences and self-esteem. The qualification ‘shared’ refers to individuals who comply with the CFR and to a certain extent share the unjustified

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beliefs. The dynamics of the CFR and the characteristic that individual members of a group can embrace or abandon the CFR, suggests that there is a propagation mechanism that allows a CFR to progress or digress through an organization.

It is assumed that this 'unjustified belief' progress very similarly as to 'justified belief' or knowledge, although the CFR is more volatile and less persistent. This is not surprising, as 'justified beliefs' are based on certain objectivity, related to the qualification 'justified' and one can say that 'justified' in the context of an organization implies that some sort of external validity has taken place.

As an example, in Case Study A described in Chapter 4, the switching mirror effect and some of its characteristics were initially observed at the university laboratory and later the experiments were reproduced, verified and validated at the research laboratory. These set of independent and unbiased experiments contribute to the justification of the beliefs concerning the switching mirrors and can be considered as knowledge. Initially the CFR does not have this 'hardness' and is considered to be subjective and therefore more prone to dynamical alterations.

Also, where for example, physics is a hard science and verification is well supported by describing the experiments and the setup that was used for obtaining the results, many social processes are much harder to verify. These aspects play an important role in the CFR; the question why something should be developed is based on a perception which is hard to verify, can change easily and influenced by many organizational factors. The volatile and subjective character of CFR is expected to give rise to differences within a group and/or other sub-divisions, including differences between hierarchic levels within the organization.

Where knowledge has certain persistence, CFR is less 'sticky' and is more dynamic. Consequently, it is expected that in order to keep pace with the temporary character of CFR, more and more frequent information exchange is required. This information exchange is not only required to obtain an organizational awareness of the current CFR of a group of individuals, but is also a necessary condition to expand the CFR over the borders of the group. In this perspective it is important to explain not only the merits of a CFR, but also the merit of the absence of the CFR.

5.2.1 The benefits of the presence of CFR

From a managerial perspective, the organization requires guidance by missions, goals and strategies. As an organization has a hierarchic structure that can not be denied, there is a risk that the strategies and policies are based on the CFR belonging to the most powerful people in the organization. Based on this managerial CFR, the expectation is that the organization operates consistently conforms to the top down policies and strategies. In the situation where the managerial CFR makes sense through

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the ranks there is no doubt within the organization about the policies and strategies, and the management vision is fully shared by all the individuals in the organization.

In the context of this research, this case is not rejected nor disputed but it is anticipated that this case is very rare and almost non-existent. A more likely situation is that a bottom up CFR is adopted by the management of the organization, although it is expected that this can be a long and sometimes painful process, as there will be a clash between the operational CFR and the managerial CFR and somehow these have to merge.

Nevertheless, the merit of fully developed in the CFR in the organization allows for highly coordinated actions, towards a fully accepted goal state. However, many contributions in literature show that the change within an organization is inevitable. The reasons for the need of change are, e.g., related to economical development in terms of emerging technologies, new markets, or other social/economical divers. In this perspective a change of the CFR can be induced either top-down or bottom-up. In a top-down situation the management of the organization has to deal with the presence of an old CFR that has to be overtaken by a new CFR.

This process takes time and comes with extensive information exchange; not only to communicate the new CFR itself, but also to change the belief related to the old CFR, to the belief related to the new CFR. It is expected that this change of belief has to provide benefits to the individual; just communicating the new CFR is not enough, the individual has to buy-in to the new CFR, implying that adapting the new CFR has certain benefits that prevails over the old CFR. This is a painstaking process especially as the new CFR does not have direct benefits for individuals, either because it is not perceived as such, or just because there are no benefits.

It is not unusual that the adoption of a new CFR breaks down along organizational sub divisions. Where individuals in one subdivision see benefits or are neutral and conform to the new CFR, the individuals in another subdivision see no benefits at all to conform to the same CFR. It is expected that the conformation is related to the belief that individuals have about the positive effect of the new CFR and that 'preaching' is required to change this belief.

A bottom-up CFR change consists of similar mechanisms. In the context of this research a bottom-up change of the CFR is quite common. For example the conception that a technology falls short to secure the development product in the future, is unlikely to happen within the management circles of the organization, but will happen rather in the mind of a technology developer who is worried that the problem solving cycles do not converge to the required goal state. This individual belief that the old CFR is inadequate will be exposed to the group of co-workers. Basically there are two possible scenarios resulting from this exposure; one scenario is that there is no obvious solution available and the CFR of the group of co-workers vanish and this will lead to a crisis.

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The other scenario is that a solution is within reach and that the new CFR can be adjusted fairly easily. In this section, the latter scenario is discussed, while the first scenario will be described in the next sub-section. The smooth adoption of a new CFR is more likely to happen if the CFR is gradually changed, the new CFR represents a logical extension of the old CFR and there is a profound belief that the new CFR will fix the inability of the old CFR to guide the problem solving cycles. In this perspective, the smooth adoption is related to gradual or evolutionary change. The group has not yet had to change their beliefs radically, and the change in their beliefs is logical and understandable and in line with the existing justified belief or knowledge base.

Although it can be argued that the impact on the rest of the organization is moderate, still the consequences for adopting the new CFR may require a different facilitation. Consequently, the management needs to be made aware of the new CFR and buy-in to the new CFR, in order to change the strategies and policies to accommodate the new CFR. It is expected that propagation of this new CFR will take place by a combination of vertical and lateral process. Based on the changed policies and strategies of the management the new CFR will be imposed on the organization similar to what has been described before in this section. The lateral propagation will also take place, but it is expected that this is based more on a functional information exchange.

5.2.2. The benefits of the absence of CFR

In the previous subsection two scenarios were discussed related to the bottom-up change of the CFR. One of the scenarios is related to a more gradual change of the CFR, which can be smoothly adjusted by the organization. This scenario will be related to evolutionary change processes. The other scenario assumes that after an individual is confronting the group of co-workers with evidence that the existing CFR is inadequate, that no obvious solution is available or known. This will lead to an emerging crisis. Initially the CFR will weaken as there is some doubt created; however it does not mean that the co-workers will directly conform to the 'unbelief'.

At the onset there will be a tendency to ignore the unbelief. The disbelieving individual will put more effort into strengthening his unbelief and will try to show evidence that the old CFR is inadequate based on logical reasons. At a certain point this notion will come upon the group which will lead to a crisis. The crisis will become evident if the CFR is fully vanished, resulting in incoherent behavior. As no obvious solution is available, the individuals will follow their own beliefs in the absence of a CFR. By doing so, the group shifts from a coherent or focused mode to an incoherent or defocused mode. Although this seems to be very chaotic to outsiders, this apparent random search for a solution serves a purpose as well. It is assumed that the crisis can only be solved by finding a solution that is fundamentally different from the previous solutions. Where the previous solutions were found in the ruling paradigm, the new

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solutions will be found in a different paradigm. This new paradigm may require new knowledge, new methodologies and new specializations. Consequently, any activities which are organized by the old CFR are ineffective and new routine breaking activities need to be deployed to search the 'solution space'. By letting the individuals follow their own beliefs, a plurality of paths will be followed, which is beneficial for the search process. Once an individual finds a hopeful trace, it is beneficial to proceed in a more organized manner by establishing a CFR that orchestrates coherency in the search activities. It is assumed that this searching for new solutions is still done by a problem solving routines; the question is how this search is driven in coherent way.

This may ask for some further explanation; several individuals who each go their way in their problem solving routines, set their own goal states result in incoherent activities, but one can ask whether there should be some common reason for these individuals to go each their ways.

It is assumed that the CFR can exist at several levels and that these levels are associated to the problem-solving cycles. This assumption leads to the following typology of type 1, 2 and 3 Collective Frame of Reference.

A type 1 CFR can be described as a Collective Frame of Reference regarding a higher level organizational objective: There is a shared belief in the organization that a certain objective is meaningful and which makes sense to pursue. In case of a paradigm shift one can say there is a shared belief that a crisis exists and that the organizational objective is to solve this crisis. Although not related to a particular crisis but rather a particular opportunity, a higher level objective was also identified in Case Study A; a display device should be created.

Individuals who conform to the type 1 CFR will work towards this higher level objective, but this does not imply that the goal states that guide the problem solving routines are necessarily the same. Referring to Case study A, individuals with very different backgrounds all worked on the creation of a display, but at a certain point in time researchers were working towards solutions in the gas phase, while others were working on solutions based on the fluid phase. The goal states guiding the problem solving cycles were very different at that time as the physical system were quite different.

A type 2 CFR can be described as a Collective Frame of Reference regarding the goal state: There is a shared belief in the organization that a certain goal state is required to obtain the higher level objective. In Case Study A, at some point in time the goal state was determined by the notion that a solid state device was required that did consist of the switching layer, and catalyst layer, a buffer and an electrode. The CFR did result in coordinated efforts to realize this concept. The problem-solving methods were not necessarily guided by this CFR; a certain state can be realized by several different mechanisms and based individual beliefs the researchers decide on which problems need to be solved in order to obtain the goal state.

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A type 3 CFR can be described as a Collective Frame of Reference regarding the problem solving routines. There is a shared belief in the organization that a certain problem solving routine should be used to realize a particular goal state that is required to obtain the higher level objective. One can say that a type 3 CFR provides highly coordinated problem solving cycles that are confined to a certain system and which supports a belief that a particular type of problem needs to be solved in order to make progress.

It is assumed that during the realization of the higher level objective, the organization migrates towards a type 3 CFR, which allows highly coordinated activities. The observations in Case Study A indicate that a type 1-to-type 2 transition took place. It is expected that a type 3 CFR was present at the end stages of the program but this period lay outside the observation window. The three types of the CFR are summarized in table 5.1.

CFR type	CFR includes higher level objective	CFR includes goal state	CFR includes problem solving routines	Description
Type 1	Yes	No	No	Higher level objective forms the coordinating element in the search activities, while the goal state and choice of problem solving routines are determined by individual beliefs.
Type 2	Yes	Yes	No	Both the higher level objective and the goal state form the coordinating element in the search activities, while the problem solving routines are determined by the individual beliefs.
Type 3	Yes	Yes	Yes	The higher level objective, the goal state and the problem solving routines form the coordinating element in the search activities.

Table 5.1: The Collective Frame of Reference typologies.

5.2.3 Overview of patterns

Based on the previous sections and sub-sections, an overview of patterns will be given. These patterns are based on the initial field studies and on elements that have been found in literature and described in Chapter 2. Still, there is some hypothetical value attached to these patterns, but with the research described in Chapter 6, the expectation is that these patterns will be confirmed, corroborated or rejected. In the overview two types of processes are considered: the CFR changing process and the process of CFR propagation process.

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Situational context	Goal state determined by	Coherency	Change qualification	Impact on organization	CFR pattern
Problem solving routines without any issues.	Strong CFR	Static, group coherency is high	No structural change is required; operation fully within the paradigm	None, all process can be applied unaltered	Full Routine, within current paradigm
Problem solving routines create some issues	Initially Individual, fast transition to modified, strong CFR	Dynamic, Group coherency is medium	Evolutionary, some gradual change is required, the paradigm will be slightly altered	Medium, some processes, policies and strategies need to be altered	Modified Routine, gradual altered paradigm
Problem solving routines create major issues	Individual, slow transition to weak CFR	Dynamic, Group Coherency vanish, may return to low level	Revolutionary, major change is required, a new paradigm needs to be found	High, CRISIS, the organization has to reinvent themselves, new processes, policies and strategies	Routine-breaking, new paradigm

Table 5.2: The CFR change pattern in a group.

In summary the following is observed:

Situational context	Driver	Goal	Main barriers	Main concerns	CFR Propagation pattern
Bottom-up propagation of CFR change	Experts opinion	Obtain facilitation, resources, budgets	Create understanding, prove necessity	Fail to explain necessity, resulting in limited management support	Expert based
Top-down propagation of CFR change	Hierarchic structure	Flow down new policies, strategies	Create buy-in, Show benefits	CFR can breakdown along organizational sub divisions	Hierarchic based
Lateral propagation of CFR change	Functional dependencies	Integrate functional functions	Create functional understanding, prove necessity	Fail to explain necessity, resulting in barriers between functional groups	Functional based

Table 5.3: The propagation patterns of the CFR

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1. Coherent, coordinated activities and incoherent, uncoordinated activities come with the presence and absence of the Collective Frame of Reference of the group.
2. The presence of a strong Collective Frame of Reference keeps the group focused on its activities and allows for coordinated problem solving routines with a CFR based goal state.
3. The absence of the CFR initiates incoherent and uncoordinated activities - this results in uncoordinated problem solving routines where the goal state is set based on individual beliefs.
4. Propagation of the CFR is based on influencing individual beliefs, and takes place internally, within the group, laterally towards functional interdependent groups and vertically, either top-down, or bottom-up.

5.3 Definition of Collective Frame of Reference

The definition of the CFR is based on the foregoing discussion and is as follows:

Collective Frame of Reference is a set of beliefs that are shared within an organization. This belief is not necessarily justified (knowledge), and can be based on shared intuition, experiences, cultures and perceptions. The CFR can propagate through groups and across organizational boundaries.

It is expected that the CFR is seldom completely shared and that all individuals in an organizational structure rarely do not fully conform to the CFR. From a management perspective this can be seen as an undesirable situation; first order management techniques assume a hierarchic structure where policies are flown down and adopted smoothly. It can be argued that a not fully adopted helps in situations where radical changes need to be made.

By having individuals in an organization who require an understanding of the benefits for the organization before they conform to a CFR, has a two-fold benefit. Firstly the top down CFR needs to be logical and understandable for the individuals, which requires clear communications and understanding and one can say that unclear and un-logical CFRs are filtered out by resistance further down the hierarchy. Secondly, individuals that require effort to let them conform to a CFR are more critical. In times of doubts and crisis it is expected that these critical minds will help taking initiatives to explore for new paradigms.

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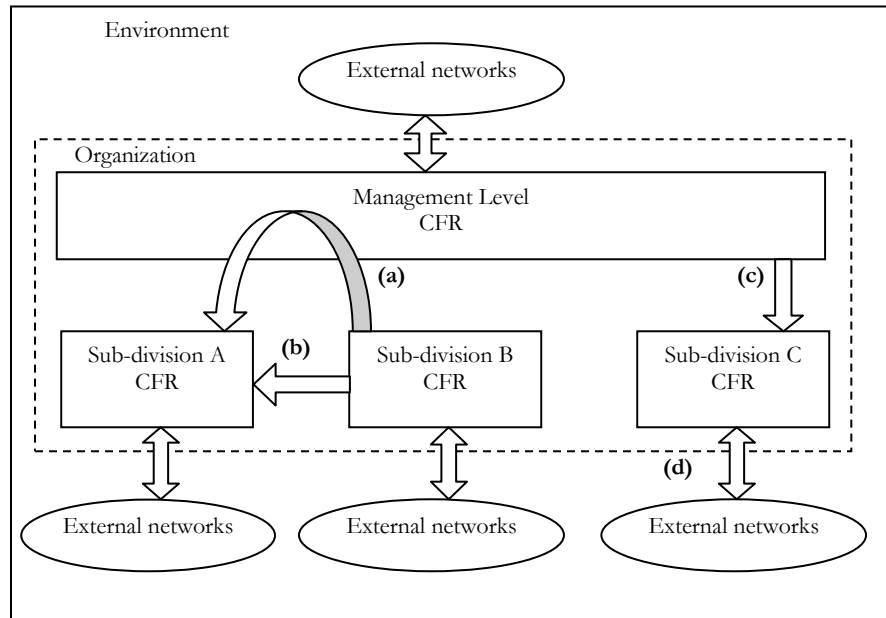


Figure 5.2: The conceptual framework of CFR **(a)** Bottom-up propagation; after management buy-in, hierarchic pattern will be following to influence CFR of other sub-divisions. **(b)** Lateral propagation; along the function dependencies the CFR from one sub-division is influenced by the other. **(c)** Hierarchic propagation; along the hierarchy line the management influences the CFR of the subdivisions. **(d)** Part of the CFR is determined by the perception of the environment. This perception can differ per sub-division as they are connected to different external networks.

In a technology development perspective, the sub-division consists of a group of technology developers or researchers and where the group's CFR is related to the technology paradigm that is followed. The CFR at the management level is related to the technology strategy that is followed. This strategy is not necessarily adequate to deal with the issues that the technology developers are facing resulting in differences in the intended and actual implementation of the strategy [e.g. Mintzberg & Waters].

In this two-level framework a distinction is made between the Collective Frame of Reference (CFR) at management level and the one on the level of the researchers, the operational level. The decision to start a technology development project and the definition of its objectives can be based on an explicit and formal technology strategy.

Typically management has the lead in defining a technology strategy. In order to be able to define a technology strategy, management must be informed on the nature and potential of the various technology options that are available to the firm. Important sources for this information are researchers themselves. However, it is assumed that

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the information given does not directly lead to a definition of a (new) technology strategy, but goes via the CFR of the management team: it is this CFR that drives technology strategy definition. Information from the operational level that does not fit the existing CFR will have difficulty in being accepted and may be discarded by management. For example, the researchers participate in various inter-organizational science networks which influence their CFRs, but the information they derive from their networks does not necessarily find its way into the board rooms.

Also there can be differences in perception on the internal abilities. In Case Study B the belief was lacking by the management level that the organization could solve a certain technical problem, so management moved to out and it started to out-source the development. It was also found that the management was confronted with two different CFRs from different subdivisions which led to a kind of ambiguity on the technology strategy to follow. The researchers have their own beliefs with respect to technology options, which may be aligned with the co-workers in the research group, creating a CFR at the operational level.

Mutual misunderstanding, sometimes even distrust, at the management level of the CFR at the operational level may make it difficult to align the CFRs at both levels. This is an issue as there is a strong mutual dependency between the groups; on the one hand the management allocates resources and budgets to develop technologies and wants to impose the top-down strategies and policies, while on the other hand the management expects creative solutions and technologies that will improve the competitive position of the firm, something that can only be achieved with a group of engaged researchers who are willing to divert to non-conformism if appropriate.

5.4 Factors comprising the CFR

The conceptual framework suggests that CFRs develop under the influence of interactions between the management level and the operational level and under the influence of internal and external factors. The internal factors include the following.

- A. Competences: The know-how to conduct certain processes. This creates a certain way of thinking that will reflect in the CFR.
- B. Technologies: The technological building blocks available to the firm, basically forming the technology paradigm. This also creates a certain view on the current technology and the possibilities to move to other technologies, which will be reflected in the CFR.
- C. Past Experiences: An organization carries the burden of historic failures and successes. In the case of failures, it imposes a certain fear factor to the CFR. In

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the case of successes and winning streaks, it will impose a “never changing a winning team” factor to the CFR which sets the routines.

- D. Past Strategies: Choices, made in the past, impose path dependency on technology development. This may explain the fact that a firm will tend to judge a side-step from the current course as more risky than persistently follow the current course. This implies that this path dependency is incorporated in the CFR.

These internal factors constitute a paradigm that is related to the CFR. It is not only about the technological paradigms, but also about the routines, knowledge and skill sets that are present within an organization that constitute the paradigm of the organization. Successes and failures contributed to these paradigms and this is a load that comes with mature organizations.

The external factors contributing to the development of a CFR include the following.

- E. Market developments: The market developments obviously influence the CFR. The upcoming and downfall of markets and globalization are factors that influence the thinking of the various actors.
- F. DESTEP factors: The Demographic, Ecological, Social-Cultural, Technological, Economic and Political factors may also influence CFR development. These macro factors create a kind of “zeitgeist” that influences the thinking and acting of individuals of organizations and groups.
- G. Competitive developments: Competition can be considered as very significant in the development of CFRs with respect to prospective technologies: companies tend to continually screen their technological options in view of a possible increase or decrease of their competitiveness.
- H. External technological factors: The upcoming and downfall of technologies that are directly or indirectly related to the technology base of the organization will definitely influence the CFR of the firm.

It is important to note that these factors do not contribute to the CFR as facts but that it is more about perceptions with respect to these factors. As said before, these perceptions can differ per sub-division in an organization off-set by differences in external networks, internal and external communications, knowledge base, demographic structure, individual backgrounds, routines etc.

Finally, four psychological and social factors are suggested that constitute to the CFR.

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- I. Values: The values of a group or individual impact on the CFR even as actors are unaware of the influence of this factor on their acting.
- J. Individual Beliefs: The individual beliefs impact on the CFR, and tend to be more volatile than values.
- K. Self Esteem: The self esteem is a perceptual view on the value that an individual or group has for its environment. This factor impacts on the Collective Frame of Reference via the confidence one has in being successful.
- L. Risk perception: The perception of risks impacts the Collective Frame of Reference and can be associated with entrepreneurial attitudes of a group or individual.

These factors determine not only the coherency of the groups and the confidence levels contributing to the CFR, but also the course of action in the absence of a CFR. These factors can work as opposing forces, e.g., an individual with high self esteem, strong individual beliefs, strong engagement and low risk perception may conform less easily to a CFR, but at the same time this individual may be very useful in leading the way in a crisis situation and find new paths for progress.

5.5 Guiding questions related to CFR in a technology development context.

As said before, the concept of Collective Frame of Reference is based on the theoretical framework described in Chapter 2 and the Initial case studies reported in Chapter 4. For the purpose of further research, some hypothetical questions about the CFR will be given in this section.

The first Question concerns CFR as shared unjustified belief:

Question 5.1: Can the Collective Frame of Reference be defined as a shared unjustified belief that compared to knowledge, is more subjective, more intuitive, more volatile and less obligatory?

CFR as ‘shared unjustified belief’ implies that it is subjective, possibly based on intuition and actually less explicit. Where ‘justified belief’ or knowledge can be demonstrated more easily, either by the explicit form or in the tacit form by actual demonstration, CFR is harder to catch. It is volatile because of its unjustified nature and from an individual perspective less obligatory; as conforming to a belief gives fewer obligations than conforming to a fact. The fact the CFR is related to unjustified belief suggests that it can become justified belief or knowledge. In this perspective it is indeed assumed that elements constituting the CFR become knowledge once this CFR

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has resulted in facts or artifacts that justify the initial belief. These elements are particularly related to the problem solving cycles. As posed before it is assumed that the CFR sets the goal state of problem solving routines, where the CFR envisions the desired outcome of the problem solving cycle. Once these problem solving cycles result in the realization of the goal state, or at least a solution which is considered as 'workable', the followed routine starting from the problem definition to realized goal state becomes a fact and reality. This reality is a contribution to the knowledge base of the organization.

Question 5.2: Can it be said that CFR can constitute to knowledge if the problem solving routines lead to the realization of the CFR induced goal state?

The creation and destruction of the CFR is correlated to the coherence or incoherence of the group. Where a strong CFR creates a strong coherence in the activities of the individual members, the absence of a CFR leads to incoherent individual motivated activities.

Question 5.3: The presence or absence of the CFR is positively correlated with the coherence, respectively incoherence of the group's activities.

Not only does the CFR propagate throughout the organization, but also the opposite; the vanishing CFR propagates throughout the organization. It seems that the CFR which constitutes a certain belief can be cancelled by 'disbelief' in terms of the lack of belief that a certain CFR fits the needs of an organization. This disbelief can also propagate through the organization, and with it a crisis propagates through the organization.

Question 5.4: Can the CFR propagate through the organization as a 'coherent unjustified belief' that settles in the minds of the individuals within the organization?

And likewise the opposite:

Question 5.5: Can a vanishing CFR propagate equally through the organization as a 'disbelief' about the whether the CFR makes sense to the organization that settles in the minds of the individuals within the organization?

Finally, the factors which influence the CFR will be posed as a question. The external and internal factors which are expected to have influence on the CFR have been discussed previously. It is interesting however to understand what the main factors are that make an individual conform or non-conform to a CFR. This subject is not new;

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Kuhn has described the phenomenon about scientists suffering from a dualism were that on the one hand they feel it is beneficial to conform to a paradigm (or disciplinary matrix) and on the other hand they want to be innovative and leave the paradigm to explore new theories.

Kuhn suggested that scientists have found a balance, which he termed “the essential tension” [Kuhn 1977]. It basically discusses what keeps an individual on track or what will get him/her off track? Along the line of this essential tension, it makes sense to assume that there is an apparent balance between the benefits for an individual to conform and the benefits to non-conform to a CFR. It is also assumed that the balance is influenced by the factors that constitute the CFR. By looking at the factors which influence the CFR, division can be made between the static, gradual and dynamic factors.

It is assumed that the most dynamic factors are most likely related to the volatile character of the CFR. One factor that is assumed to be the most dynamic is individual beliefs. Where factors, comprised of a knowledge base, past experiences, values etc., are relatively static or gradual, individual belief can change relatively fast, which makes it the most likely candidate to be responsible for the dynamics in the CFR. So can addressing this individual belief keep individuals either on track or force them off track?

Question 5.6: Is individual belief a factor that is responsible for the dynamics in terms of conforming or non-conforming to a CFR?

The six guiding questions will guide the discussion of results and reflection on the results in later Chapters.

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Chapter 6: Main Case Study

“..the shared picture of the organization must be reinforced continually, especially by checking that it is in fact entering into the decision making process”¹⁵

Chapter 6: Main Case Study: The Dynamics of the Collective Frame of Reference

In Chapter 5 the concept of Collective Frame of Reference (CFR) has been introduced based on theoretical considerations and on observations of two initial case studies that are described in Chapter 4. In this Chapter the result of a case study is described, which is designed to study the patterns and characteristics of the CFR. A sub-division of a mid size Technology Intensive Organization is entering a reorientation phase as a result of a lack of confidence that the current deployed technologies are sufficient to maintain the competitive position. There is a sense of urgency to introduce a new technology as a remedy to restore the competitive position and restore the confidence that the organization can sustain. The reorientation phase starts from a position where very limited knowledge is available and during the course of several brainstorming sessions, more and more information is gathered and processed, towards a decision. During these sessions, the CFR has been measured and observed, from which certain patterns have been deducted.

6.1 Case study C: On the brink of a paradigm shift

In order to observe the patterns of the CFR in a situation where the organization shifted from an existing paradigm to a new paradigm, it was important to start observing an organization that was entering a reorientation phase. In this case study, an organization entered this reorientation phase after a take-over by a mid-size, North American TIO. Before the take-over, the organization belonged to a product division of a large multinational TIO, as described in case study B. While the organization was initially waiting for directives from the parent organization, it started to feel stronger competition in several areas of their product portfolio. The pressure was very intense and perceived as a direct threat to the current business and sustainability of the organization. This provided a sense of urgency to change in order to restore the competitive position. The main concern was that the current technology, which the organization was exploiting, was not providing enough product performance compared to competing products.

¹⁵ Simon in ‘Strategy and organizational evolution’ 1993 [Simon 1993]

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6.1.1 Research design

In order to get more insight into the Collective Frame of Reference as defined in the previous Chapters and in its role in technology development, a case study has been designed in which the development of collective frames of reference could be observed. The case study design was based on the ideas of Yin on exemplary case studies [Yin 1994]. Following Miles and Huberman, a four-step approach is used throughout the case study [Miles & Huberman 1994].

Data collection: Field notes were made in participative observation during the various processes that played in the case study.

Data reduction: The field notes were written down in a 'write-up', a running story in which the observations are put in perspective.

Data analysis: From the write-up, the patterns that were considered to be relevant were highlighted, coded and binned. The results were written down in analysis sheets and data displays.

Drawing conclusions: From these patterns conclusions were drawn and propositions concerning patterns, entities, events and interrelations were formulated.

The case study essentially followed the development of a new technology strategy in which the main issue was whether or not to start the development of a new technology. During the reorientation process a number of workshop sessions played a crucial role. In these workshops both management and researchers participated. They were very intensive and time consuming, but at the same time very in-depth and revealing. The advantage of the use of a series of workshops was that there were really meaningful discussions and intense exchanges of knowledge and information.

At the same time this made it possible to observe the creation and destruction of the Collective Frame of Reference with respect to the new technology. By registering the opinion of the members of the group on certain propositions with respect to various options, development of a Collective Frame of Reference was measured. After every session a number of propositions were presented to the group, after which it was observed whether there was a unified or divided reaction and how the discussions, initiated by the propositions, proceeded. The same propositions were in some cases presented in later sessions, which could reveal the dynamics of the development of the Collective Frame of Reference.

6.1.2 Case setting

The organization in this case study evolved from the one which is described in case study B. After being part of a large European multi-national where a product line specialized in professional imaging, the organization became part of a mid-size North American Technology Intensive Organization. The reason for the sell was that the large multinational made the strategic choice to provide high volume products to the market.

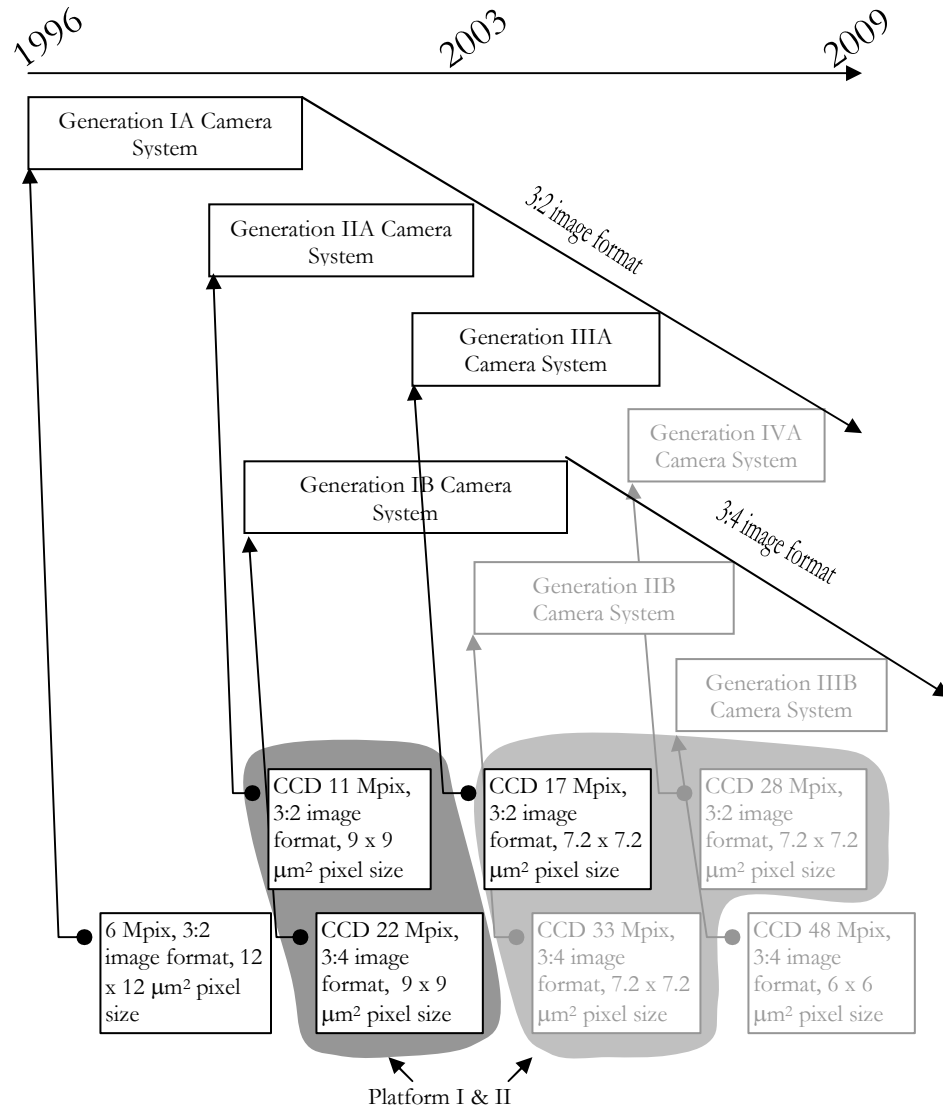


Figure 6.1 The product roadmap of the organization described in case study C. These products are provided to products on a system roadmap. The organization needs to ‘win’ design-ins to be successful. For some products platforms are utilized, where design blocks are reused for several products (e.g. platform I and II)

Initially the organization became part of this scheme and attempts were made to develop and manufacture High Volume image sensors based on a Charge Coupled Device (CCD) principle.

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The main market focus was on the Consumer Digital Still Camera (DSC) market. This market was characterized by low cost camera offerings and production in large volumes. Although this group had a long history in developing technologies for the CCD devices and was one of the front runners in development after the invention of the CCD in the late 60s, it lacked the technologies that were particularly suitable to be applied in low-cost and high volume image sensors. After the Product Division of the European Multinational realized that the current technologies were insufficient to support the strategic direction, the Product Line did no longer fit the strategic intend. The Product Division was not interested in the Professional markets that could be served by the technologies of the Product Line and offered the Product Line for sale.

A mid-size North American TIO bought the Product Line as part of a strategy not only to expand the markets, but also to become more vertically integrated. Aside from the product technologies, the process technologies that were acquired with the Product Line were of particular interest to the new owner. It provided, together with a semiconductor process fabrication facility that was acquired in the same year, an independent source of image sensors that the acquiring firm had lacked before.

As a supplier of a key component, the case study organization had to keep pace with the roadmap of the Professional Digital Camera system. In general, manufacturers of camera systems work with a system roadmap where several generations are identified. This is done for different applications and leads to multiple roadmaps. For a supplier it is important to obtain a so-called design-in for every product on the roadmap. Missing such a slot, results in losing the customer for about two years and consequently a gap in the revenue for this particular product occurs.

The reduction in revenue makes it harder to recover the development costs. Figure 6.1 shows the roadmap of the organization prior to the reorientation process for a particular market; the professional Digital Still Camera markets. It shows the products that were developed or under development. In retrospective the follow-up products up to 2009 have been indicated as well. The organization utilized a platform approach, where design blocks were reused for several products. This platform approach allowed for faster developments and shorter time to market [See e.g. Halman 2003].

The new organization is described in Figure 6.2. The activities of the group are focused on the development, design and production of professional image sensors. These sensors are applied in High end imaging applications like broadcast cameras, Medical X-ray systems and High-end studio Digital Still Cameras. The group has a very common line organization where Manufacturing, Research & Development, Marketing & Sales and Test development are represented in a Management Team headed by a General Manager. The manufacturing was based on a semiconductor foundry model; the designs of the devices were processed by the proprietary foundry in North America. After receiving the processed silicon wafers the devices were further manufactured in the European organization.

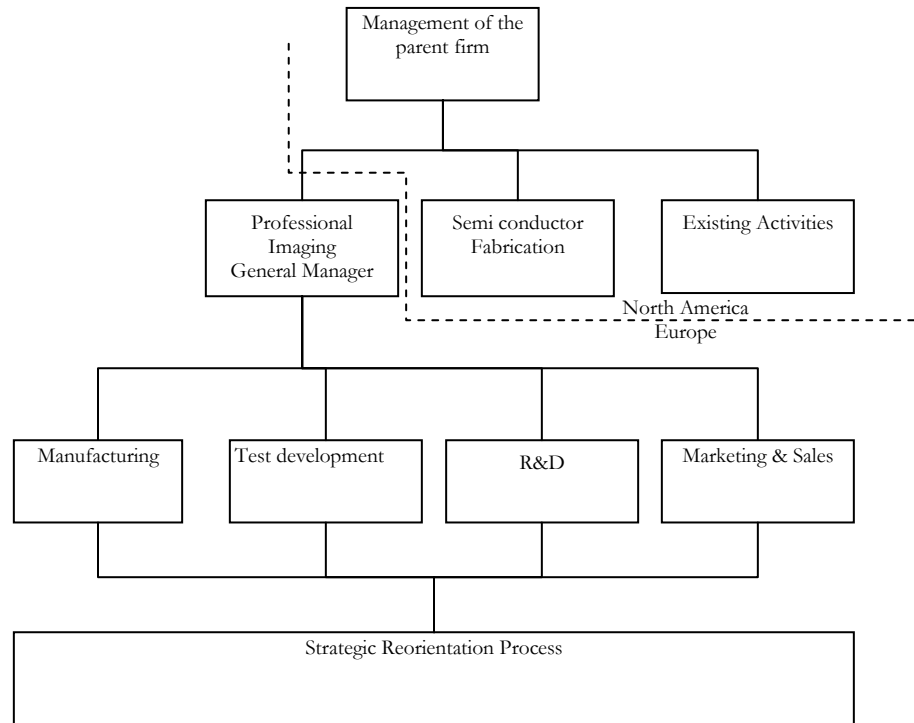


Figure 6.2: The organization structure of Case Study C

6.1.3 The reorientation process

Central to this case study is a reorientation process with respect to the strategic options of the organization in general and the technology options more specifically. This process took place about 7 months after the organization was taken over by the North American TIO. The R&D department and the Marketing & Sales departments were initiating the Strategic Reorientation Process which originated from the perception that the organization entered a dead-end with its technology compared to other competitors.

A few large customers turned away, and several design-in slots seemed to be lost. The reorientation process was a structured process, in which senior management and participants at the operational level participated in a work group. This work group had the task of conducting the reorientation process and form strategic options that later

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could be deployed not only in the form of technology development projects and product development projects, but also in organizational development processes. Table 6.1 gives an overview of the participants of the workgroup and the primary function that they fulfilled.

Corporate Head quarters (overseas)	Main function in process
Chief Technology Officer	Providing Corporate Input
Senior Management level	
General Manager	Process Principal
Marketing Manager	Initiator, provider of market data
Research and Development Manager	Initiator, provider of technical data
Manufacturing Manager	Provider of manufacturing process data
Manufacturing Engineering Manager	Provider of Test and Assembly technical data
Operational level	
Project Manager Product group A and process Technology development	Provider Technical input, application knowledge product group A
Project Manager Product group B	Provider Technical input, application knowledge product group B
International Product Manager Product Group B	Provider market information product group B
Account Manager Product group A	Provider market information product group B
Research Project Leader	Provider technical input, process facilitator

Table 6.1: An overview of the participants and their function in the reorientation process (after the acquisition)

Table 6.1 shows the three levels in the organization; one is the corporate level, which was represented by the CTO: one is the management level and the other is the operational level. The CTO held office at the organization's premises and represented the parent organization and provided technology input from the corporate level. During these sessions information was exchanged between the management and operational level. The participants at the operational level represented two product groups. The product group B in particular raised concerns as the customers were turning to the main competitor for their next generation product and several design-in opportunities were missed. Product group A was identified as a growth market, and the reorientation process was used to determine strategic options to develop more efforts in this market area. The orientation process consisted of several structural steps. The process that has been followed is depicted in Figure 6.3

The reorientation process flow that has been followed started with an orientation on both the organization and the environment. In this case the environment comprises the markets, competitors and so-called DESTEP factors (Demographic Environmental Social Technology Ethical and Political factors). During this orientation phase the members of the workgroup are actively gathering information to form a perception on the markets, competitors and on trends in society as well as their own organization. These perceptions were registered by means of a SWOT-analysis (an analysis of

Strengths Weaknesses Opportunities Threats). Based on this analysis the core

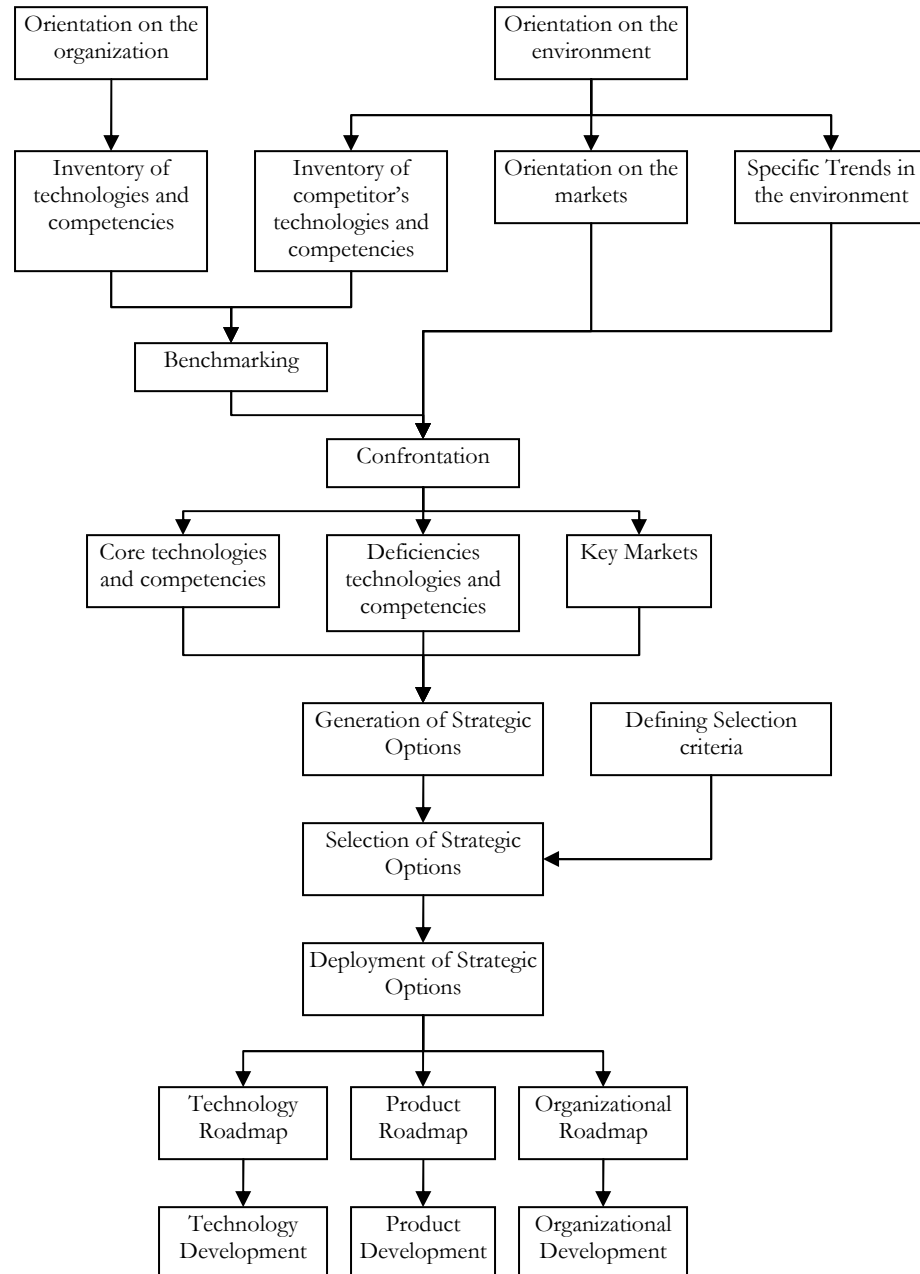


Figure 6.3: A schematic representation of the reorientation process.

technologies and capabilities were identified and the key markets were determined.

Also, the deficiencies in technologies and capabilities were identified. From these three elements the strategic options were generated and later selected. The selection criteria for the strategic options were based on the mission and goals of the organization. The mission of the organization was discussed as part of the reorientation process. The deployment of strategic options took place in the form of feasibility studies towards certain technologies and markets. From this the Technology roadmaps and Product roadmaps were defined and executed. Although less explicit, the organization was changed to accommodate the new technologies and products. This was not done based on an explicit roadmap, but evidentially the organization was adapted to the new strategy. To structure the data, a correlation matrix methodology (see figure 6.4) was used very similar to the ones used in the Quality Function Deployment methodology (see e.g. Akao 1990).

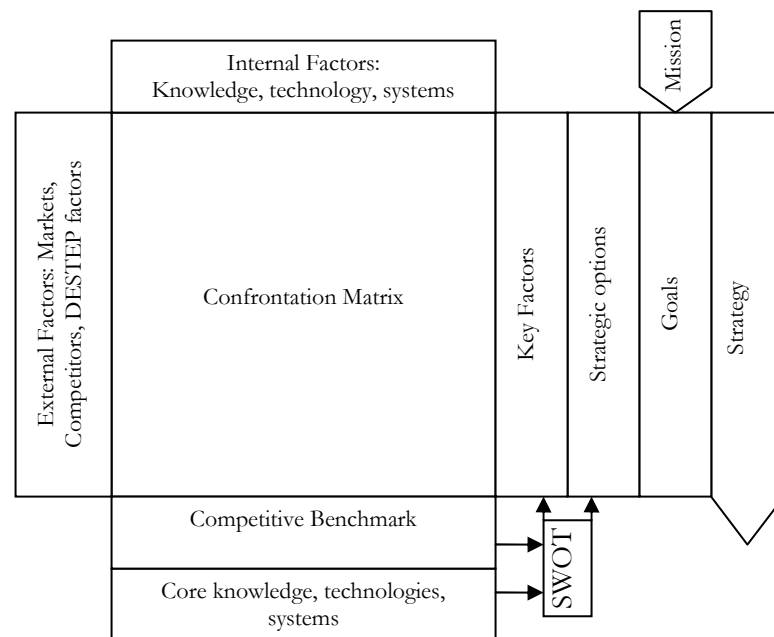


Figure 6.4: The adapted QFD methodology that has been used for the data analysis.

6.2 Observations

The followed process was not so much the focus of the case study observations. The main interest was to observe the group processes and the changes of the CFR. This

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suggests that the CFR is measurable and observable. During the course of the reorientation process, several propositions were presented to the group and the reactions were registered. This registration was not limited to the verbal response only but also attempts were made to capture the attitude of the group. It is expected that this gave important additional information about the coherence of the response. The propositions were shown instantly to the group and there was no foreknowledge. During the process of showing the propositions attempts were made to register how the group responded to the propositions. The qualitative indicators which were identified are given in Table 6.2.

Indicator	Response	Attitude	Interpretation
Mixed/heedful	Incoherent	Thought full	Longer time to initial response, initial response leads to limited incoherency, some discussion takes place, expressions of thoughtfulness and/or doubts
Mixed/swift	Incoherent	Confident	Shift response, clear incoherent counter response, discussion takes place, defending opinions, expressions of firmness
Aligned/heedful	Coherent	Thoughtful	Longer time to initial response, initial response results in more coherent responses, coherency after discussion, expression of thoughtfulness
Aligned/swift	Coherent	Confident	Shift response, clear coherent responses, expressions of firmness
General remark on proposition	Incoherent/ Coherent	Confident	Some propositions resulted in a remark about the formulation; Some of the negative formulated propositions were seen as 'too negative'

Table 6.2: The indicators that characterized the response on the propositions presented to the work group during the reorientation process.

The statements were both negative and positive. For example, “The organization can...”, and “The organization cannot...” In some cases the statements were repeated in later sessions. It is assumed that those indicators reflected the CFR during the reorientation process and that the response on the propositions reflected the status of the CFR in time. Although this is an assumption it can be argued that the response on the propositions reflects the beliefs of the group at that particular moment. It showed whether the group shared a certain belief and a qualitative measure how strong this belief was at a particular time. It is this ‘unjustified’ belief that has been is related to the CFR according to the findings in Chapter 5.

Description of observations from the reorientation phase

The reorientation process started by the forming a work group that followed a scheme of ten bi-weekly work sessions, which were used to exchange information, to brainstorm, to analyze data and discuss the findings. In this section an overview is given of the observations during the sessions.

Session 1

In this session the environmental factors have been identified. During this session a negative self-image surfaced after it became apparent that customers were turning down the organization's products. There was a general perception that the current technology was not sufficient to remain competitive. The impression was that the organization should consider the CMOS imaging technology as an alternative to the current CCD technology. For two product groups this technology was considered in particular. Product group A aimed at a professional market in which the organization wanted to expand, while product group B aimed at a market where the organization's position was under a directly perceived threat. During the session a brainstorm was exercised, elaborating on the external factors. This included the DESTEP factors as well as market trends and characteristics of competitors competing with the product groups A and B. Specifically for product group B the main competitive forces were identified.

Session 2

During the second session the results of the first session were presented and discussed. The focus of this session was on the technologies that are required to support product group B. These technologies were benchmarked with competing technologies as have been deployed by competitors. In the second session the group was divided on how the data should be structured and this led to an extensive discussion about the process rather than about the content.

Session 3

The third session started with the presentation of some definition about knowledge and technology and competences in order to obtain a better distinction between those terms. With those definitions in mind the data presented in session 2 was reviewed and structured. There was still a sense of urgency noted about the need to change the technology. In this perspective the technologies deployed by the organization were not only benchmarked with similar technologies deployed by competitors, but also with more different technologies, like for example CMOS.

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During these first sessions it became apparent that the work group developed the perception that CMOS would be superior compared to the older CCD technology. This perception resulted in a preference to focus on CMOS in the next sessions.

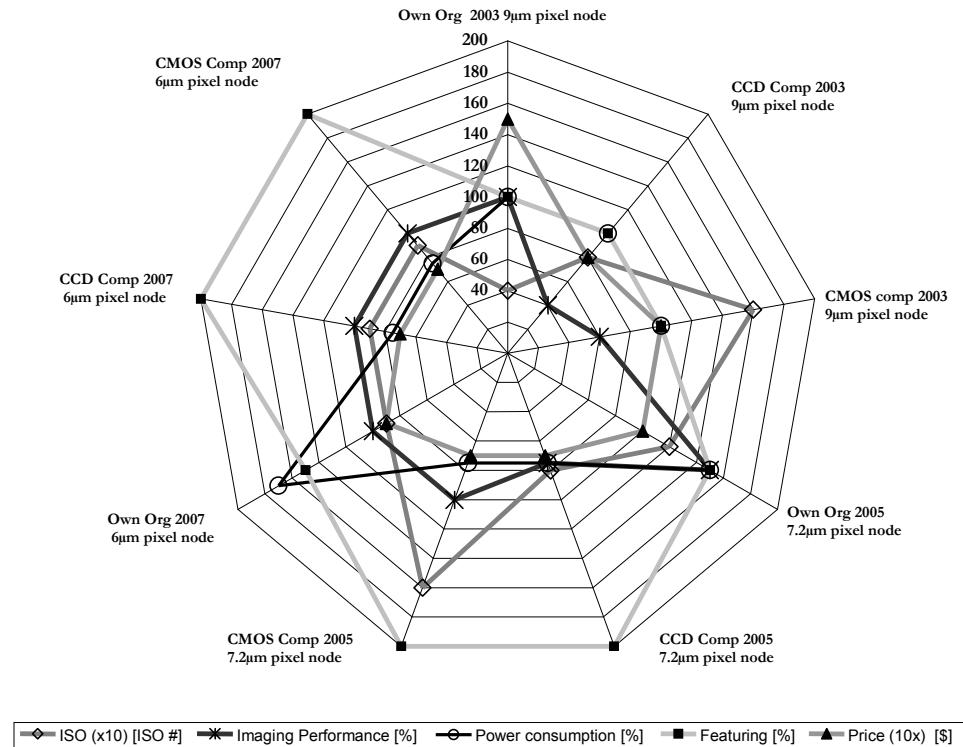


Figure 6.5: The Radar plot with a forward prediction of various technologies with 2 year intervals.

After the session a radar plot was made of the performance of the pixel technology in relation to a CCD competitor and a CMOS competitor. This plot shows the perceived performance of the organization in relation to a competitor utilizing the same CCD technology and a competitor with the 'new' CMOS technology. Aside from the current status (2003) projections have also been made about the trends in the observed performance parameters with 2-year intervals (2005 and 2007). Some analysis of the plot shows that the organization is pessimistic about the performance at the time the analysis was done in 2003; their products were more expensive and less performing compared to the competition. Also it was observed that the CMOS technology would become better.

Session 4

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In the fourth session the modified QFD methodology was presented as a data structuring tool. In order to set the proper goals, a review of the mission of the organization took place. The normal sequence for a Mission-Goals-Strategy intervention according to the method described by Weggeman [Weggeman 1995]), was not followed here. The existential questions discussed to define the mission did not occur. It was not until almost half way through the strategy development process that the mission was actually discussed. This can be seen as a backward fix of the normal sequence.

So far the mission of the organization was kept out of the reorientation, but it was later seen as essential to consider the function of the organization within the parent-organization. The Mission-Goals-Strategy intervention did guide the goal-setting and proper selection of the strategic options in a later stage. Although the function of the organization within the parent-organization was not entirely clear and under discussion, the mission, goals and strategy of the parent-organization were reviewed.

Session 5

The first part of the fifth session was focused on supporting technologies and competencies. Capabilities like manufacturing, supporting technologies like sensor packaging (see, e.g., case study B) and the Marketing and Sales channels were reviewed and benchmarked to competitors. During the second part of the session the CMOS technology was discussed. This was done based on prepositions that were presented to the work group. The response on these prepositions were registered and analyzed. The propositions that were presented were the following:

- CMOS Imaging is the greatest threat for the product group B.
- The organization has all the competencies to produce CMOS sensors.
- The organization needs CMOS to grow.

During this session the response to the proposals was coherent and persistent; there was no doubt that the organization needed to shift to the CMOS paradigm. There was a clear idea that the organization could support this shift. The spirit in the work group could be characterized as optimistic towards the organizations ability to shift the new technology.

Session 6

The sixth session was further devoted to the assembly processes and other enabling technologies and capabilities. These capabilities were benchmarked with other divisions in the parent organization and with competitors.

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Session 7

In the seventh session the markets of product group A were discussed. The perception was that the organization had a very limited presence on this market despite the huge potential. It was recognized that the knowledge about this market was limited and this was reflected in the brainstorm sessions.

Session 8

In the eighth session the discussion about the market for product group A was continued and did focus on a new CCD product. For this product group CMOS was not considered as a necessity and the organization considered that the CCD technology would still be capable of satisfying the needs for a specific market served by product group A.

Session 9

In the ninth session, new information was brought to the table concerning CMOS.

	Total relative Performance	Price/performance	Price	ISO Speed	Image quality	Innovation level
CCD now	100%	100%	100%	100%	100%	100%
CMOS now	104%	100%	110%	80%	95%	130%
CCD + 4 years	108%	110%	110%	120%	105%	105%
CMOS + 4 years	133%	130%	130%	110%	105%	180%
CCD + 8 years	117%	120%	120%	140%	110%	110%
CMOS + 8 years	165%	170%	160%	140%	110%	240%
Remarks: For all data: the higher the number the better the score	Mean score of the indicators	Performance of CMOS is expected to go up and prices are likely to go down due to scale enlargement (8" to 12")	See remarks in left column	The noise of CMOS sensors is expected to reduce in the future, either by direct (process improvements) or indirect (noise compensation)	The CMOS image quality is expected to become equal w.r.t. CCDs	The CMOS concept is expected to give more opportunities for innovative applications, e.g. features

Table 6.3: The benchmark of two different technologies now and in the future.

This information was gathered to benchmark the current CCD technology and the new CMOS technology. This table initiated a lot of discussion and divided the group. The

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proposition gave a mixed response especially on the required efforts to adopt the new technologies.

The main discussion was about the cost of ownership for the organization and some members had the impression that the cost of ownership of the new technology was significantly higher than what was stated in the table, while other members thought it should be equal or even lower.

Session 10

The tenth and final session was devoted to the role of the organization within the new parent organization in North America. This role was discussed in terms of business models, technology development and dependencies. The role of the CTO in this matter with respect to coordinating the technology development efforts was discussed in particular.

Cost Item	CCD	CMOS	Remarks
R&D Effort			
Design Library	100%	150%	The development of a new CCD process is considered to take a similar effort as design dedicated CMOS imaging blocks
Process Development	100%	50%	
Packaging	100%	100%	Extra de-coupling necessary for CMOS?
Wafer price	100%	100%	CCD 6", CMOS 8"
Cost of Ownership	100%	125%	(once the process is available) CMOS sensors require more design effort
Yield	50%	70%	Total Yield Large area (35 mm) device with similar functionality on-chip
Dies per wafer	100%	200%	CCD 6", CMOS 8"

Table 6.4: The cost factors of the two technologies

Post workshop observations

After the workshop sessions, the business situation improved for the CCD products. In an effort to develop additional features and further down scaling of the image pixels, the CCD technology got an extended lifetime, along the paradigm. Concerning the CMOS technology, the management of the organization had the impression that the paradigm shift was too big a decision to take independently and relayed the decision to the head quarters of the parent organization. Despite this escalation of the technology decision, a dedicated technology assessment was initiated towards the potential of CMOS technology for product group A applications.

Within the parent organization a subdivision was already working on CMOS but the focus was different from the needs of the European organization. Within a year after the last workshop, a group of CMOS designers and engineers had been acquired and

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had been incorporated within the European organization. This acquisition concerned the CMOS Intellectual Property and several CMOS experts.

The CMOS group focused mainly on product group A applications, rather than on product group B applications. Actually, there was a CMOS project initiated for Product group B, but that failed due an incompatibility of requirements and the lack of available external process capabilities. For product group B, the CCD technology is still used. There is currently a competitor that uses CMOS for product group B applications, and on the longer term it is still expected that this technology will play a more prominent role in the product group B markets.

6.2.1 Longitudinal time line case study C

The time line of case study C shows reorientation process. The total process from reorientation to implementation took place over a period of 2 years

Week 14 2002 → Transition from the European Multinational to the Mid-size North American TIO.

Week 47 2002 → First strategy workshops
Main Goal: Orientation on the environment
DESTEP analysis

Week 03 2003 → Second strategy workshops
Main Goal: Results and feedback of the first session
Consensus about definitions and process
Established distinction between technologies and competences

Week 5 2003 → Third strategy workshops
Main Goal: Technology Assessment
CCD vs. CMOS
Plotting expected technological developments for CCD and CMOS technology

Week 7 2003 → Fourth strategy workshops
Main Goal: Mission-Goals-Strategy
Mission of the Organization
Structuring of the Reorientation Process
Brainstorm sessions Market, Competition factors for product line B

Week 12 2003 → Fifth strategy workshops
Main Goal: CMOS as threat and opportunity

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Brainstorm sessions Test capabilities and Marketing & Sales for product line B
The potential of CMOS for Product line B, both as threat and opportunity

Week 14 2003 → Sixth strategy workshops

Main Goal: Enabling technologies

Brainstorm sessions Package and Assembly technologies incl. benchmarking

Key package and assembly technologies for Product group B

Week 17 2003 → Seventh strategy workshops

Main Goal: Orientation on Markets Product group A

Brainstorm sessions on key markets and customers for product group A

Required technologies for the key markets

Week 19 2003 → Eighth strategy workshops

Main Goal: Selection of Markets Product group A

Brainstorm sessions: Required capabilities and Technologies for selected markets

Strategic options for Product group A

Week 24 2003 → Ninth strategy workshops

Main Goal: CMOS discussion and Strategic Options

Brainstorm sessions CMOS developments, Market developments product line B

CMOS for Product line B as Strategic Option

Week 27 2003 → Tenth strategy workshops

Main Goal: Role of the Organization

Brainstorm sessions Role in the parent organization

The role of the organization for Technology developments

Week 44 2003 → Presentation of the Final Results Workshop sessions

Main Conclusions Recommendations to Management:

Technology base is worn out for product group B

Technology lags behind main competitors

Build up a Long Term technology base.

More (application) knowledge is required to expend product group A

Build up knowledge about CMOS

Week 44 2004 → Charter for Feasibility Study CMOS based products for product group A.

Main Goal: Study the market product group A and an assessment of CMOS in this market

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Study available competing technologies
Study market needs
Assess the CMOS technology towards the market needs

Week 47 2004 → First CMOS technology workshop Product group A
Main Goal: Technical discussion CMOS based product
Brainstorm sessions: Technology Assessment
Discussion about the Technology roadmap

Week 48 2004 → Second CMOS technology workshop Product group A
Main Goal: Technical Analysis
Identification of gaps in knowledge base

Week 50 2004 → Third CMOS technology workshop Product group A
Main Goal: Presenting Results Technology Analysis, Trends and Concepts
Brainstorm sessions Test capabilities and Marketing & Sales for product line B
The potential of CMOS for Product line B, both as threat and opportunity

Week 52 2004 → Presentation new CMOS based technology for product group A
Main Conclusions Recommendations to Management:
Potential for CMOS based products
Presentation of CMOS Based Product Concept
Presentation of Market/Technology trends
Critical dependencies

Week 09 2005 → Final report CMOS technology for product group A
Final report
Creation of an implementation plan
Information session at the overseas HQ

Q3 2005 → Incorporation of CMOS technology
Acquisition of CMOS assets from third party and recruiting CMOS designers
Transfer of application knowledge to the new CMOS resources within the organization

2006 → Development CMOS technology prototypes
Start development prototype product group A
Start development prototype product group B

2007 → Technology demonstration
Prototype product group A is functional, results shown to target customers
Start product development for Product group A.
Prototype product group B is not functional due to process problems

2008 → Deployment of CMOS technology
First product samples completed

6.3 Analysis

In this case study an organization is observed that had been part of a large European multi-national organization before it was acquired by a smaller North-American organization. After the acquisition, the management of the organization started a process of reorientation. The reason for this reorientation was tri-fold:

- The organization became aware of an imminent threat as customers indicated that their products were not considered for the next design-in slot.
- The organization was placed in a new environment; from the relatively sheltered position in the large multinational, the organization needed to adapt to its new role within the new parent organization.
- The organization wanted to evaluate what the consequences of the North American management style were in general and, in more specifics, what the new corporate culture was.

The parent organization required a growth plan, in order to comply with the corporate growth planning. This request urged the management of the organization to develop a strategy for growth.

The organization obtained information that their customers were turning towards the competition, mainly because of performance reasons.

The latter consideration gave the organization a definite sense of urgency to take immediate action. Losing the design-in window from several customers would have an impact on the mid-term financial position. The organization considered new technologies in order to make their product range more competitive. Aside from incremental and more significant developments within the so far utilized CCD technology, CMOS imaging technology has also been considered to strengthen the technology portfolio. Although CMOS technology has been around for some time, this technology can be considered to be new for this organization.

Several workshops were organized to support the decision-making process to overcome the crisis. In these workshops both management team members and researchers participated allowing for a decision making process that was constantly fed both management and technical input.

The workshop followed a 'helicopter view' approach: starting at a high altitude, the work group orientated on the environment and then, lowering the altitude, zoomed in more and more on the details.

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During the workshops several trends in the environment were identified. An approach was followed to distinct the so-called DESTEP factors within the organization's environment by identifying Demographic, Economical, Social, Technological, Environmental and Political trends. From this analysis the work group members created a common perception on the environment. This common perception contributed to an initial CFR that formed a background for the following processes.

After establishing an orientation on the environment, the work group focused on the organization and realized that the organization had to reposition itself after the acquisition by the new parent organization. In order to define its mission, the workgroup started to discuss the existential questions of the organization. It needed to be understood which role the organization wanted to play within the parent organization. The organization needed not only to adopt the new overall corporate mission, but also define the role or mission within the parent organization. This step allowed the organization to derive the goals and strategy from the mission later on in the process. Again, the common perception on the organization mission contributed to

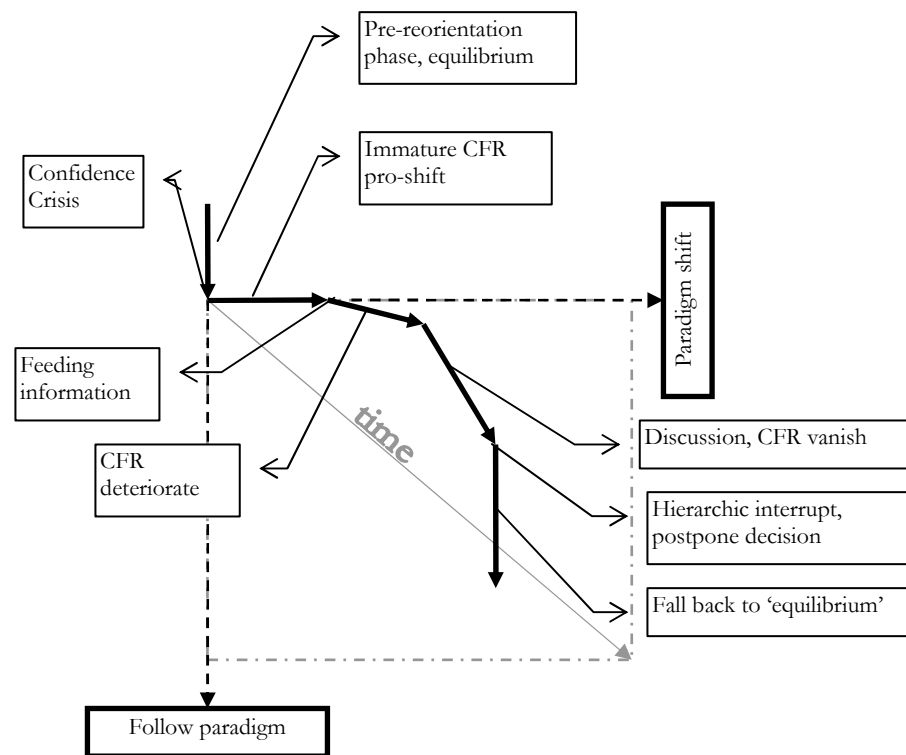


Figure 6.6: The observed creation, deterioration and destruction of the Collective Frame of Reference

the 'background CFR'.

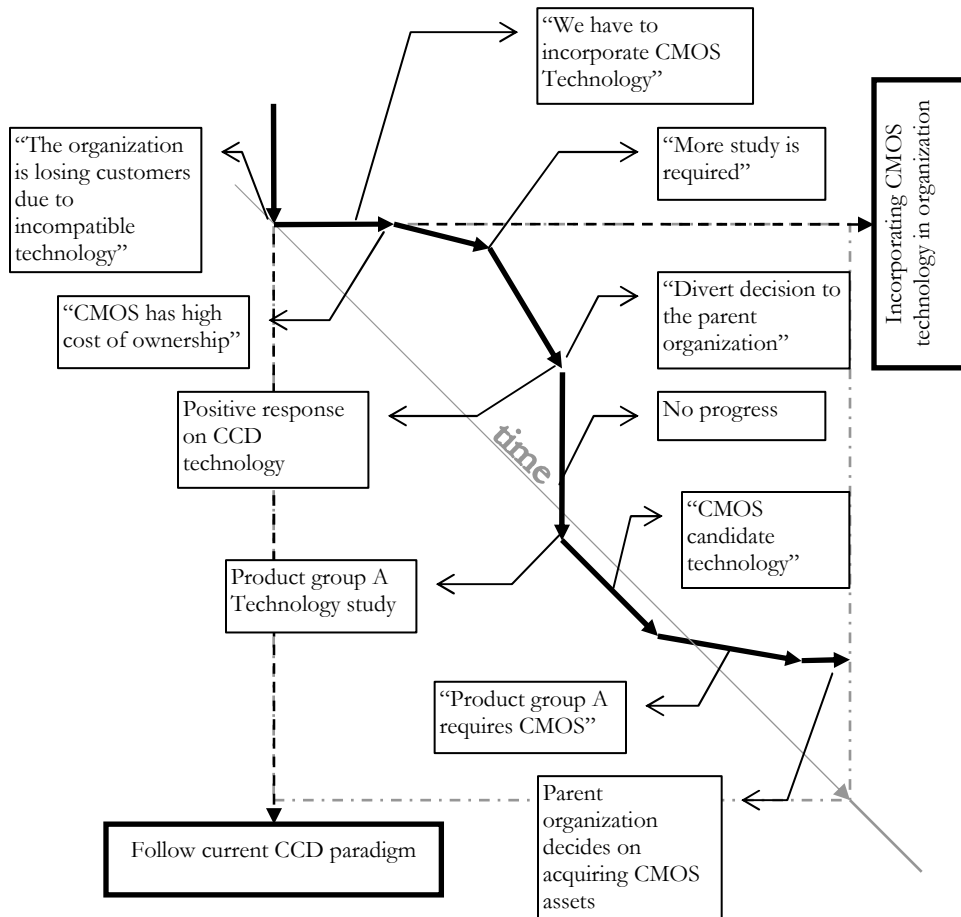


Figure 6.7: The flow of the CFR (between quotes) and events during the course of the paradigm shift.

In more detail the markets of two product groups were analyzed in terms of competition and future needs. These observations were intertwined with a discussion about the technological options that the competitors were utilizing and the impact on the performance that was required by the market. This analysis was done in a forward looking fashion so that the progress in performance of their own technology and those of the competitors were estimated at intervals of two years for the coming four years. The impact of the technological options, including CMOS, was benchmarked forward looking.

At first the prospects of the CMOS technology seemed to be good which resulted in a level 3 collective frame Collective Frame of Reference (see Chapter 5, Section 5.2.2) Reference that strongly supported the obvious choice to implement this new technology. However, this CFR proved not to be mature, and by bringing new information about CMOS to the table, the CFR was affected. The new information resulted in lively discussions and resulted in a vanished CFR; the group was split and the CFR was scattered. What remained was a level 2 CFR where the participants agreed on the goal state, i.e. obtaining access to CMOS, but there was no CFR on the means to obtain the goal state.

The principle of the process exercised a 'hierarchical interrupt' by stating that the decision should be left to the parent organization. This decision coincides with more positive news on the chances of winning design-ins with the current technology; apparently the initial pessimistic image about the status of the current technology could

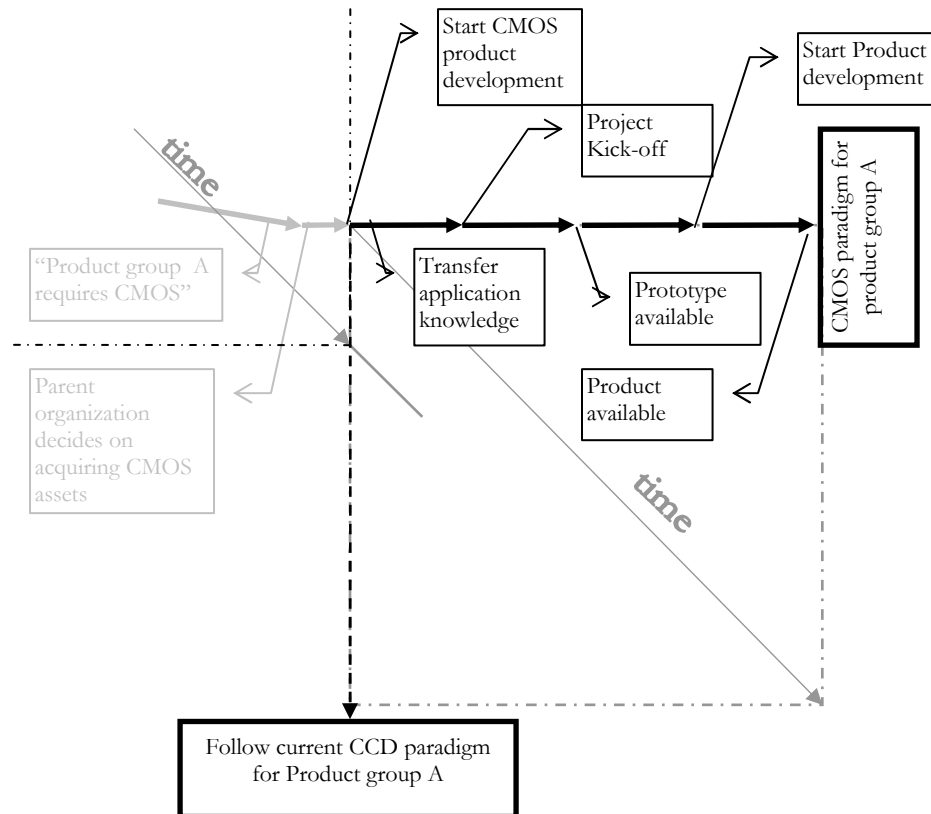


Figure 6.8: The course of action for product group A after access to CMOS technology.

be adjusted to a more optimistic image. After this the organization fell back to its equilibrium state as before the reorientation.

It is expected that this pattern is generic and applies to many other decisions. An organization that has or wants to break free from a paradigm starts with incomplete knowledge about the new paradigm. The CFR based on incomplete knowledge, can lead to ill-fated decisions, while new information can deteriorate the immature CFR easily, leading to an opposite decision.

Another possible mechanism is that in order to stimulate the change to a different paradigm, a 'false' sense of urgency could be created. For example, by creating negative future prognoses and pretending that the organization is entering a real crisis, a motivation for change is created. It cannot be excluded that this mechanism has been used by individuals and/or groups to stimulate the organization to enter a reorientation phase. If this initial data is 'corrected' by more specific analysis, the motivation to change paradigms is reduced and the organization falls back to its equilibrium state.

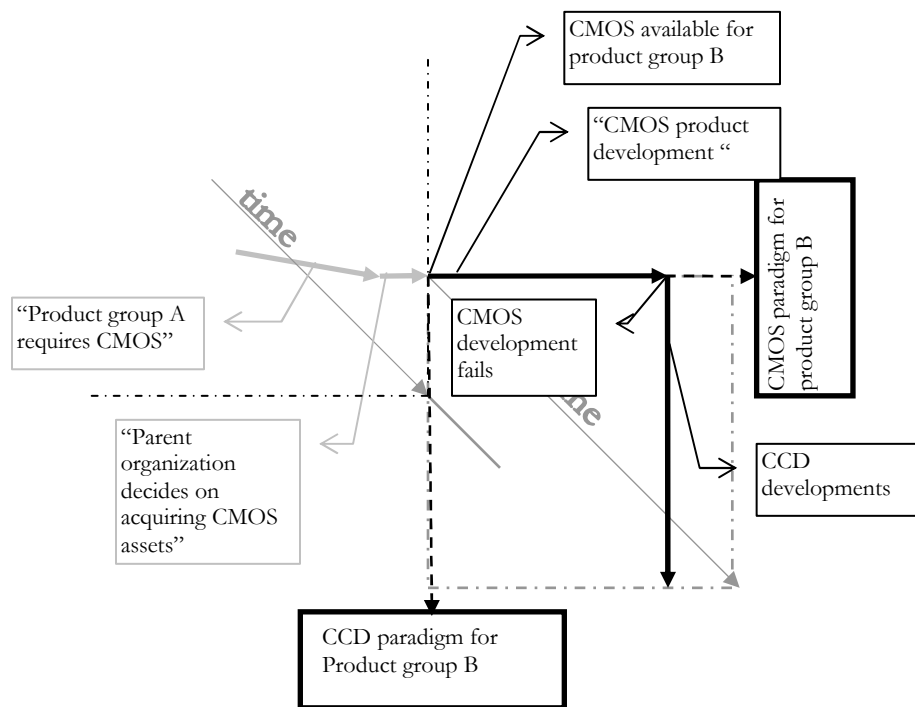


Figure 6.9: The course of action after access to CMOS technology for product group B; a product was developed and failed. Product group B shifted back to the CCD paradigm.

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In conclusion the CFR should be mature enough, i.e. based on complete information, before the decision is made to leave the paradigm.

After falling back to the equilibrium state, the option of incorporating the new technology was not fully rejected, but the management of the subsidiary organization perceived the impact of the paradigm shift too large to be considered independently. Therefore the organization left the decision to the parent organization.

For a period of about a year there was no real progress. In the meantime, other drivers emerged to reconsider the paradigm shift. The organization considered to expand their activities in the product group A market space. The current products were CCD based but it was concluded that this technology imposed limitations on the market size. Therefore a feasibility study was initiated to examine not only the market needs but also assess the technologies that were available. From this study it was concluded that CMOS was a valuable technology and would be a driver to expand the activities in product group A. This result contributed to the decision by the parent organization to acquire CMOS assets to be incorporated in the European organization. Figure 6.7 gives a graphic representation of the main events and activities up to the paradigm shift.

Once CMOS resources were incorporated in the organization, programs were started to develop process technologies and critical design blocks for both product group A and B. After the first results of the programs, Product development programs were started for products in both product group A and product group B. The product group B development failed due to incompatible requirements of the CMOS IC processing process. The product group A development resulted into a product from which currently products are delivered.

It is striking that the course of events led to a situation where product group B fell back to the CCD paradigm while the CMOS discussion was initiated to secure future products for this group. Product group A, however, did shift to CMOS while initially it seemed appropriate to stick to CCD technology.

6.3.1 Analysis of the CFR characteristics

Multi-Level structure

To a much lesser extent than in case study B, the differences of the CFR at the management and the operational level became visible. One of the reasons is that for the reorientation project, members at both levels were involved which resulted in coherent behavior at both levels and clear differences in CFR on these levels were not observed.

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Dualism

During the reorientation phase no real dualism was observed. Again it seemed that the cross-organization process provided options to every member to align activities. It was, however, observed that individuals played different roles in the reorientation process. Members at the operational level mainly fed the process with existing and new technological knowledge. This influenced the CFR considerable. There was some dualism observed by people that were more open to change than others. Some members did not see the need to consider CMOS and were very optimistic about further advances in CCD technology; others were very much in favor of CMOS as it was new and exciting. These differences were noticed but did not lead to noticeable incoherent actions.

Non-Conformity

In the initial stages a strong CFR was observed which supported the development of CMOS technology. This CFR appeared to be immature however because the CFR deteriorated after individuals shared new information. Apparently, some members felt uncomfortable with the 'immature' CFR. These members decided to provide additional information to the process and not conforming to the existing CFR. These actions were tolerated but could be seen as disturbing for the process as it could affect the existing CFR. However this information contributed to a more mature or changed CFR and therefore can be typified as 'functional' non-conformity.

Divergent-Convergent Phases

The reorientation process had divergent and convergent phases. It was found that during the convergent phases the CFR was widely carried by the workgroup. In divergent phases the CFR was more scattered and resulted in individual actions. These actions were not unplanned however; the workgroup did not take these individual actions into account. The individual members seemed to align their actions in line with their stance towards the CFR.

Personal Beliefs

Personal beliefs also played a role in this case study. It was observed that some people felt uncomfortable with the CFR. It did not mean that they did not accept the CFR but felt uncomfortable with its maturity, for example due to the limited information the CFR was constituted on. Based on the belief that the CFR was not mature enough, these individuals started to collect additional information, which either resulted in a changed CFR or an more mature CFR

6.4 Patterns of Collective Frame of Reference

The analyses of the main case supported the ideas on the role of collective frames of reference, developed in case B and C: collective ideas on the nature and potential of new technologies support focused decision making and actions on technology development. However, a certain Collective Frame of Reference is not necessarily a stable one. It can disappear, causing defocusing of behavior after which a reorientation is needed to obtain further progress.

6.4.1 The creation and destruction of collective frames of reference

Triggered by the need to find a promising new technology the members of the workgroup aligned their ideas on the potential of CMOS technology and this resulted in a positive Collective Frame of Reference. This shared belief resulted in a wide support for the decision, "We have to incorporate CMOS technology". It seemed that some members had felt that the CFR was based on a too limited knowledge base. At a later workshop new information on CMOS was presented, especially with respect to a significantly higher cost of ownership. This destroyed the CFR within the work group and some members had doubts whether CMOS could be implemented as easily as initially assumed, while others did not see that it would be different from the current CCD technology. The perspective of this discussion was how much effort was required to build up the new technology. One part of the group was optimistic and thought that this effort would be limited and manageable by the organization while the other part was more pessimistic about the effort and thought that the organization could not resource such an effort. This caused quite some friction within the workgroup.

It seemed that the principle of the process felt less convinced to make a decision on incorporating CMOS in the organization independently. Further interactions via additional workshops lead to revoke the implementation decision but it was still decided to do further studies to increase the knowledge about CMOS technology. At this point in time, the collective frames of reference were again aligned. These further studies led to the conclusion that both the investments and the risks associated with CMOS were too high to take decisions at the level of the research group and, as discussed above, the decision was escalated to the parent organization.

6.4.2 The maturity of a Collective Frame of Reference

It was found that a Collective Frame of Reference can be achieved in a mature and premature fashion. At the first workshop a Collective Frame of Reference was developed, but several group members still were uneasy with this CFR. This is an indication for a premature CFR. It was these individuals, uncertain of the quality of the CFR, who acquired the additional information and presented it to the group, not necessarily to destruct the existing CFR but at least to improve its quality and make it

more mature. A mature Collective Frame of Reference should be able to withstand to a reasonable extent new information and doubt.

6.4.3 Openness to information

To which extent a group allows new information to change its Collective Frame of Reference is expected to be of great importance. If the extent is obstructed, the risk of creating a premature CFR is high. It is in this perspective also important that some group members are willing to look for information, either contradictory or not, and present this for the group. A group member may need a well-developed self-esteem to overcome the barrier to bring information into the group that contradicts a developing CFR. This has been called non-conformist behavior in case C. One can also see it as a management responsibility to keep a CFR open to new information, to allow some non-conformist behavior, especially in its early stages of development.

The concept of CFR has many similarities with the concept of groupthink of Janis (1972). However, there needs to be a distinction between an open and a closed CFR: a CFR for a research group needs to stay focused in its technology development but it should be a sufficiently open one, open to new information that may challenge the present CFR.

6.4.4 The structure of the Collective Frame of Reference

In an attempt to analyze the structure of the Collective Frame of Reference, three levels can be identified. At the deepest level psychological and socio-cultural factors play a role, determining issues like the way information is processed and the degree to which new information is allowed to change existing thought patterns. These factors are relatively stable for a given group, represents the cultural roots of the group, which hardly change if the CFR changes: the new and the old CFR may share the same psychological and socio-cultural structure of the group and the change influence this background only marginal.

At the next level the knowledge base plays a role. This knowledge base is gradually built up, and will change over time, but this is a process that takes effort and is not fluctuating quickly.

At the third level, beliefs can fluctuate rapidly and therefore can change rapidly that may relatively change the strongest and the fastest. For instance, in the second workshop of the case study described in this chapter, additional information was made available to the group. This information changed the belief of the group strongly and one can say that the knowledge basis was changed by this information but without specific verification of this information, this change can be assumed to be relatively small. Likewise one can argue that the changes at the deepest level are changed hardly by the new information. Therefore it is argued that the dynamics of creation and

destruction of collective frames of reference are the most pronounced at the level of beliefs.

6.5 Punctuated Equilibrium and Deep structure

The case study described in this Chapter shows that an organization can shift from equilibrium where the current technology paradigm is followed, to a punctuated period where a change of paradigm is realized. This connects very well to the punctuated equilibrium Theory. The findings in this Chapter show large resemblance with this theory and therefore will be discussed in particular. This resemblance is not unexpected as the equilibrium theory is related to the paradigm theory from Kuhn, which has been discussed in Chapter 2 in more detail.

Shifting technology paradigms is found to follow a punctuated equilibrium process: focused sequences of problem solving cycles that represent evolutionary technological developments along an existing paradigm, punctuated by periods of reorientation leading to revolutionary changes, resulting in a shift to a new technology paradigm.

Anderson and Tushman did a longitudinal study towards dominant designs in the cement and microprocessor industries and found basically this punctuated behaviour where dominant designs evolved until a breakthrough was realized. [Anderson & Tushman 1990] In this thesis it is argued that the CFR plays an important role during the reorientation process, and therefore it appropriate to consider the link of the CFR with the deep structure of the organization.

The concept of deep structure, described by Gersick, seems to be connected with the idea of a Collective Frame of Reference [Gersick 1991]. It is hypothesized that the presence or absence of a Collective Frame of Reference influences the choices that a group or an organization makes with respect to a certain technology and that the dissolution of the Collective Frame of Reference enables or forces the organization to switch to a state of revolutionary change. As stated by Gersick, such a switch entails a change of the deep structure of the group or organization. Therefore, CFR and deep structure seem to be connected.

Based on the description by Gersick, the deep structure can be identified with the 'organizational paradigm'. This would imply that an organization that enters a punctuated phase actually changes paradigms very similar to the technology paradigm described in this Chapter. The CFR is driving this paradigm shift. Consequently the CFR drives the change in the deep structure of the organization.

This connection and the identification of the deep structure with the organizational paradigms allows to assume that the deep structures at the several levels are influenced by each other and that a change of the deep structure at a given level will initiate changes in the deep structure at the other levels. That the deep structure is specific for several entities within the organization is similar to the earlier notion that subdivisions

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of an organization follow different paradigms as those subdivisions have different functions within the organization. This is expected to be similar for the deep structure as well.

The following sequence illustrates how the deep structure is changed starting at an individual level, via the organization and inter-organizational networks to society. An individual who has a certain unjustified belief starts to generate knowledge that will change the deep structure. This newly generated knowledge provides the individual with a new perspective and new insights that result into a new deep structure or paradigm. By participating in a group this knowledge is shared with others and may affect the Collective Frame of Reference of the group. If the CFR constitutes within the group, one can say that the group has a shared unjustified belief that the new paradigm provides particular advancements compared to the previous paradigm. It is assumed that the shared belief of advancement is a necessary condition to obtain a paradigm shift. The paradigm shift implies that the deep structure of the organization will change.

The CFR needs to propagate throughout the organization so that all parts of the organizations that are affected by the new paradigm will adopt the new paradigm and change their deep structure accordingly. This implies that the CFR acts as a change agent not only throughout the organization but also beyond the organization boundaries. Subsequently, if required the organization will need to impose the CFR to its user network, in order to get the new paradigm accepted. On an individual basis the frame of reference can be transferred to other networks via publications and scientific interaction. By this mechanism the new paradigm can be transferred to other organizations after the CFR is accepted. In further interaction, this CFR and the related new paradigm can become unified within society, provided that the paradigm has meaning for society.

According to Gersick this paradigm shift may happen in a revolutionary mode, although in many cases the revolution will be confined to the parts in the organizations or network where the paradigm has serious impact on the deep structure. Occasionally, paradigm shifts have a large impact on the deep structure of society and are typified as 'revolutions'.

6.6 Conclusion Case study C

Negative developments in a key market did drive the need for reorientation and it was perceived that the continuity of the organization was at stake which provided a sense of urgency to change. The organization concluded that the existing CCD technology could not provide a solution for the next generation products. Actually, some major customers in the key market were moving to the main competitor. The organization entered into a crisis situation, resulting in a reorientation process to look for new technologies that are better suited for the main market.

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The reorientation phase was accommodated with a series of workshop sessions. During the workshop sessions a work group of members from both the management level and the operational level were participating in the reorientation process. The reorientation process comprised a reorientation on organization itself and on the environment.

Initially the shift to CMOS technology was seen as inevitable and low risk, while later, while more information was gathered, some members of the group believed it was more difficult and risky. This coincided with the creation of a CFR initially, which deteriorated after new information became available. The lack of a CFR led to postpone the decision on incorporating CMOS and led the decision to the parent firm.

The initial CFR was considered to be immature as it was based on limited knowledge about the CMOS technology. The openness to information is considered to be very important for the reorientation process, as it prevents decisions based on an immature CFR.

The CFR can propagate throughout the organization and is expected to reach every subdivision of the organization that attaches a certain meaning to the CFR. This propagation of the CFR is a change agent throughout the organization and beyond as user groups, suppliers, and other stakeholders may be impacted by the change.

The punctuated equilibrium theory can serve as a framework for an organization that moves from equilibrium, where it follows an existing paradigm, to a reorientation process that is punctuated and leads to a new paradigm. With this paradigm shift, the deep structure of the organization is changed. The deep structure, which can be identified as an organizational paradigm, is changed by the CFR and the changed deep structure propagates throughout the organization with the propagation of the CFR.

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Chapter 7: Reflections on CFR

“Such self-co-ordination of independent initiatives leads to a joint result which is unpremeditated by any of those who bring it about. Their co-ordination is guided as by ‘an invisible hand’ towards the joint discovery of a hidden system of things.”¹⁶

Chapter 7: Reflections on the concept of Collective Frame of Reference

In this chapter, the findings in the previous chapters concerning the Collective Frame of Reference are compared to literature. A scan through the available literature shows that many factors related to the CFR are mentioned and discussed but so far the discussion lacks to date much of a structure or consensus is lacking. Although many authors indicate that these factors are of great importance, there does not seem to be a structural approach to study the concept of Collective Frame of Reference, nor similar concepts, nor elements related to the CFR. Part of establishing the concept of CFR is to embed the concept in the existing literature.

The discussion in this chapter is limited to four streams of literature, although it has been noted that there are many more streams that relate in one or more ways to CFR. The four streams in this chapter however, form the main backbone of the innovation/technology literature in both the organizational and economical tradition. Also in this chapter, connecting elements between the CFR and the TO-model, the punctuated equilibrium theory and path dependency will be explored on basis of the available literature.

The breadth of the four research questions formulated in Chapter 1 of the thesis covers multiple fields in economics, philosophy and management studies. However, this study focuses on some particular areas of interest; technology development process, path dependencies, and in context of the previous areas, the path breaking mechanisms. The conclusion that the Collective Frame of Reference plays an important role in these areas is particularly discussed.

7.1 Discussion of Collective Frame of Reference: Connections with literature

Evidently a very important question that surfaces from this thesis is: What is the Collective Frame of Reference? The term ‘Frame of Reference’ is known in psychology and cognition. A loose definition has been found where ‘frame of reference’ is defined as a complex schema of unquestioned beliefs and values which infers to meaning¹⁷. On changing the frame of reference it is implied that ‘If any part of that frame is changed

¹⁶ Micheal Polanyi in the “Republic of Science: Its political and economical theory”, Volume 1, 1962, 54–74.

¹⁷ This reference has been found on the website: <http://changingminds.org>, a website with an unknown/unsubstantiated merit.

(hence 'reframing'), then the meaning that is inferred may change'. This suggests that reframing is associated with changing the CFR. Reframing is used in the context of dealing of conflicts, where parties have different frames of reference and where reframing is required to resolve the conflict.

A more formal definition has been found where frame of reference is defined as: The context, point of view, set of presuppositions, assumptions, evaluative criteria in so far as they form a cognitive system with which a person perceives, judges or selectively constrains a course of actions or outcome thereof or with which a scientific observer delineates the subject matter of his theory. [Krippendorff]

A literature review has shown that elements that constitute the CFR are mentioned in many different publications, streams of literature, contexts, and nomenclatures. Also many phenomena have been found that are similar but used in a specific context. This makes it hard to support the concept of Collective Frame of Reference by literature; not only because of the implicit description, but also because it covers multiple bodies of literature. With the risk that only limited ground is covered, the scan in literature has been limited to four areas in literature: The evolutionary economic literature, the organizational change literature, the knowledge generation literature and the group behaviour literature. For each of these streams, concepts and elements of CFR are discussed in the following sections.

The definition given in Chapter 5 relates the CFR to 'shared unjustified belief', which suggests that the CFR is closely related to knowledge, which can be defined as 'justified true belief' [See discussion Nonaka 2009, p.639, Nonaka & Takeuchi 1995]. In relation to individual and groups problem solving, it is believed that the CFR is setting the goal state as an input to the problem solving process. This relates the CFR to progressing technology developments along a technology paradigm, which links to evolutionary economics [e.g. Nelson & Winter 1982], dynamic capabilities [e.g. Teece 1996] and organizational path dependencies more general [e.g. Sydow 2009]. From a CFR perspective, Polanyi identifies this with self-coordination in his "Republic of Science", which he calls the "invisible hand"¹⁸ that provides a self coordinating mechanism driving a group of individuals in a certain direction [Polanyi 1962]. Polanyi relates this to tacit knowledge [Polanyi 1966], which again is related to knowledge, knowledge generation and learning in organizations [e.g. Argote 2003]. On a negative note, this self-coordination relates to a phenomenon like Groupthink; why go operations wrong? [Janis 1972], while on a positive note Weick relates it to a collective mind; why go operations right? [Weick 1993]

The many links to different streams of literature shows that the CFR concept is discussed in different contexts and forms, which complicates developing a clear

¹⁸ It must be assumed that the "invisible hand" refers to the "invisible hand" of Adam Smith introduced in his "Wealth of Nations"

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definition of CFR. With some overlap though, four streams have been defined that link to the CFR in some sort of form (see Figure 7.1).

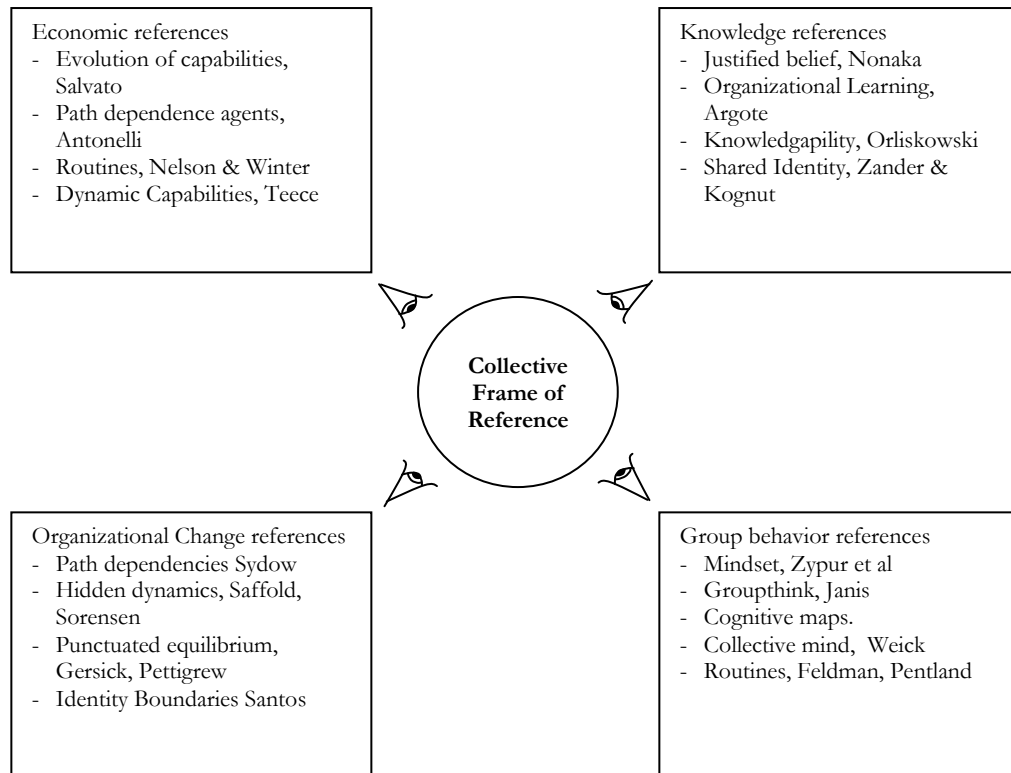


Figure 7.1: Four groups of references related to Collective Frame of Reference.

7.1.1 Evolutionary Economic References

Dynamic capabilities are defined by Teece as “The ability to sense and then seize new opportunities and to reconfigure and protect knowledge assets, competencies and complementary assets with the aim of achieving a sustained competitive advantage” [Teece 1997]. An important question is what lies behind the ‘sense’ and ‘seize’ and how do path dependencies line up with this ability. In an economic perspective, capabilities, which are interpreted as ‘learned and stable patterns of collective activity’ [Salvato 2009, p.384], can be traced back to the evolutionary path that the organization has followed. Felin and Foss found that organizational agents’ behaviour and knowledge are driven by the organizational routines [Nelson & Winter 1982,] and capabilities [Felin & Foss 2005].

Collective Frame of Reference in Technology Developments

As capabilities are, in general, seen as collective entities [Winter 2003, Zollo & Winter 2002], it seems that these capabilities carry elements of the CFR. However in the 'dynamic capabilities' framework it is unclear how the psycho-social aspects of the CFR are related. Also, a recent publication of Augier & Teece, suggests that altering the capabilities is merely a management task and not so much a multi-level group effort process. Salvato however, concludes that changes in dynamical capabilities originate from on-the-job individuals and that management reacts to the changes based on the process performance.

Nooteboom et al. defines the concept of cognitive distance that is based on a broad definition of cognition, which constitutes perceptions, proprioception, sense making, emotions, value judgements and even feelings [Nooteboom et al. 2007, p.1017]. Furthermore, cognitive distance is related to the organizational focus, which is determined by the path-dependent developments. Nooteboom gives notion of the concept of 'organizational focus', which is established by 'means of shared fundamental categories of perceptions, interpretations and evaluation inculcated by organizational culture' [Nooteboom et al. 2007, Nooteboom 2000]. These elements that Nooteboom et al. describes resemble the definition of Collective Frame of Reference given in Chapter 5, which is repeated here:

- Collective Frame of Reference is a set of beliefs that is shared within an organization. This belief is not necessarily justified (knowledge), and can be based on shared intuition, experiences, cultures and perceptions. The CFR can propagate through groups and across organizational boundaries.

7.1.2 Knowledge Generation References

Although the jury is still out on how knowledge is created, the emphasis is that it is a social process [Nonaka 2009], which still leaves open how this social process takes place. The generally accepted assumption that Technology development is basically the generation of knowledge, places this research in the context of knowledge generation in organizations. Accepting this equality would result in the emphasis that technology development is a social process. This research provided some insight in the (social) processes that take place during the creation of and decisions about technology.

The creation, destruction and propagation of the Collective Frame of Reference are thought to be drivers for the creation of technology. In Chapter 5 the Collective Frame of Reference is defined as shared unjustified belief, which related it to knowledge defined as justified true belief [See discussion Nonaka & von Krogh 2009 p.639]. Consequently, the difference between knowledge would be related to 'justified' versus 'unjustified'. This difference can mainly be related to the fact the CFR comprises many subjective, implicit shared cognitive elements, like perceptions, self-image, self-

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esteem (see Chapter 5, section 5.4). This makes the term justified almost meaningless; perceptions, self-esteem, etc, can hardly be characterized as justified as it is highly subjective and therewith excluding the identification with knowledge. It is true that, especially in technology development, decisions are driven by hard evidence which de facto results in justified beliefs concerning particular elements.

However, there are two notions to make here: firstly, one could say that a justified belief requires some external, objective test. Even when certain facts are internally proven it may not necessarily be justified; there are examples of organizations applying the wrong methods, theories etc. even when the 'right' information was relatively easily to obtain. However because of this strong collective belief that the organization dealt with the subject properly, nobody took the effort to doubt the belief. This situation, where the CFR reinforces itself in such a way that it results in a failure to access external information, can be seen as an instance of the "Groupthink ubiquity" which Baron identifies [Baron 2005]. Secondly, one could say that if solid evidence is available, the belief can be interpreted as knowledge, rather than an exponent of the CFR.

The other difference is that the knowledge definition, as discussed by Nonaka and Takeuchi as 'justified true belief', includes the term 'true'. Again, for the same reasons it is hard to connect the CFR to the objective truth, while knowledge tends to strive for the truth. Nonaka and von Krogh address this specifically in a recent publication [Nonaka & von Krogh 2009]. Assuming that CFR does not equal knowledge, it is important to explain what the connection between the two is. The proposition is that the CFR drives the creation of knowledge.

The simplest indication for this is based on the notion that knowledge is created by problem solving and the notion that knowledge creation is a social process, and the CFR is setting the goal state of the problems solving process. This would assume that the goal state of the problem solving process is socially constructed. This seems to be connected to the The Social Construction of Technology (SCOT) by Bijker et al [Bijker 1987, Pinch & Bijker 1987]. This field of study gives insight into how the environment perceives a technology that is embodied in an artifact. It illustrates how some technological concepts die while others survive and evolve further over time and therewith establish the evolutionary approach of technology development suggested by Nelson, Winter and Dosi.

This would assume that within the organization a social construction mechanism takes place, which can be seen as a pre-selection. This pre-selection is based on a perception of the selection criteria of the environment outside the organization, and therefore not necessarily equal to the actual selection criteria that evolves or diminishes a technology. Based on this assumption one could say that CFR and SCOT are two mechanisms which are related: SCOT represents the actual, external selection mechanism, while CFR contains the organizational perception of the selection process governed by SCOT. This would explain two important issues. Firstly, it explains how external

selection factors from society are imposed on the organizations that provide solutions to the market. Secondly, it explains how organizations can bring products forward that are not appreciated by the environment as a result of an inadequate perception.

Dougherty describes 'images' present in the organization that are responsible for the success and failure of innovation in the organization [Dougherty 2001]. The apparent inability to create a shared image that coordinates the actions of actors hampers organizational wide processes like innovation. Dougherty comes to the following main conclusions; a shared image of work in an innovative organization is different from non-innovative organizations. The shared image of the innovative organization is focussed on problem solving in the broader context of the innovation process, while the shared image of the non-innovative organization is focussed on maintaining the current system. At an individual level Dougherty found that individuals in innovative organizations cannot only imagine well what they have to do, but also understood what others will do.

In non-innovative organizations this is fundamentally different - individuals cannot imagine sufficiently what and how to do their tasks effectively. Dougherty also concludes that adopting a new image is a necessary but not sufficient step; the organization needs to accommodate the new image with meaningful structures that facilitate and apply this new image. The image concept of Dougherty seems to be related to CFR, although the context is slightly different from technology development. Dougherty applies this image also on the way that innovation is organized. In this research this aspect is not studied and/or observed. The assumption that the CFR drives technology development seems to be in line with the notion of Dougherty, relating the presence of an image in innovating organizations. This research was executed in innovative organizations, which relates well to the findings of Dougherty, although the success of the innovation was not particularly studied.

It is argued that the CFR contains elements of a shared ideal; based on the perceived self-image of the organisation it seems logical to assume that with this self-image comes with a certain expectation about future prospects. This is also seen as an important notion in relation to the setting the goal state which as mentioned before is determined by the CFR. By definition engaging in problem solving cycles is an attempt to shape the future prospects.

Orlikowski studied the role of knowledgeability in distributed organizations. Knowledgeability is presented as the ability to drive action, and which is highly dependent on the context, agency and structure. It is a capability that can guide collective efforts and it is fluid, virtual and provisional. Orlikowski concludes that driving activities in an organization is not only based on skills, leadership, infrastructure, the mission of the organization, but also on 'know how to do'. Relevant to CFR is the notion that knowledgeability seem to be related to a shared identity, that Orlikowski relates to Kogut and Zander's knowledge-based view of the firm [Kogut & Zander 1996]. Kogut and Zander states that the shared identity of organizations

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“provides a sense of community by which discourse, coordination and learning is structured”. Also related is the organizational identity defined by Dutton and Dukerich [Dutton & Dukerich 1991, Dutton 1994] as a shared set of beliefs about what the organization is. This is thought to be related to CFR where the collective unjustified beliefs constitute what the organization is and how it should develop.

The CFR seemed to be related with organizational memory [Moorman & Miner 1997]. The stored knowledge in an organization is considered as an asset which should be explored. This bias can also be connected to the path dependency of the firm's technology. A different technology demands new knowledge and devalues to a certain extent the stored knowledge, which comes across resistance of the conservative elements in the organization as a more specific exponent of resistance against technological change [e.g., Symon 2005].

Closely related seems so-called Transactive Memory (TM), which forms a shared system that closely interacting individuals develop to process information. It relates to organizational learning [see e.g. Argote 1999, 2003] and the ability of the organization to mobilize the knowledge of the individual group members by creating systems to exchange and integrate this knowledge in group's processes. Many studies towards TM have been based on laboratory experiments, and more recent also computer simulations have been done to study the performance of the group as a function of the TM [see, e.g., Ren 2006]

More specifically, Argote studied learning in organizations and how knowledge is generated, retained and transferred. Argote refers to organizational learning curves showing that recurring processes in organization leads to more efficiency, which is based on evidence that the required efforts decline for recurring tasks, as has been observed with the building of products of the same type. Interestingly, organizations can also forget; knowledge can depreciate when the recurring character becomes disturbed. Another interesting phenomenon is organizational memory, which allows the retention of knowledge in the organization. This memory is distributed over people, technologies and structures and routines. The final notion of Argote is group learning where the important factor is that a group with diverse members or minority views leads to higher generation rates of new knowledge.

Tsoukas relates the dialogue process to the generation of new knowledge, stating that productive dialogue allows for self-distanciation, opening the way to reconceptualization [Tsoukas 2005]. Tsoukas relates this reconceptualization to three process; Conceptual Combination, Conceptual Expansion and Conceptual Reframing. The relation to CFR is not very obvious, although it is expected that non-conforming individuals interact with other members in the organization to ‘promote’ their alternative ideas. It is expected that the dialogue process plays a role in the propagation of alternative CFRs in the organization.

7.1.3 Organizational Change References

Heracleous and Barrett studied organizational change from a linguistic perspective and distinguish two, dynamically interrelated levels; the surface level of communicative actions and a deeper level of discursive structures [Heracleous & Barrett 2001]. These deep structures are defined as 'rhetorical enthymemes' or logic, but provide no explicit reasoning that guide actors interpretations and actions. In their study, Heracleous and Barrett found that resistance against a particular change in an organization originated from the 'deep structures' of the stake holders. Despite the fact higher level communication were utilized to implement the change, a persistent deep structure driving the actions and interpretations of the actors. The CFR is thought to be similar to the deep structure in the context of Heracleous and Barretts work. It represents the forces that keep actors moving along an existing paradigm, rather than considering a new paradigm. Heracleous and Barrett suggest that the deep structure requires changing in order to redirect the organization.

Smircich studied the role of shared meaning in relation to the stability of an insurance company and found that the development of a shared meaning facilitates coordinated action [Smircich 1983]. Smircich argues that this shared meaning is developed through symbolic processes were rituals, slogans and particular vocabularies.

Sydow mentions that self-reinforcing processes in organizations result from (a) emotional reactions such uncertainty avoidance and inter-group revenge, (b) cognitive biases, e.g., selective perception, blind spots, implicit theories, and (c) political processes, e.g., gaining power, maintaining power, and reciprocal negotiation. Based on the fact that technology development is a path dependent activity and that the CFR is seen as instrumental to focus the organization to progress along the path implies that the self- reinforced process is related to the CFR. Indeed the elements that are thought to constitute to the CFR have significant overlap with the emotional reaction, cognitive biases and political processes mentioned by Sydow [Sydow 2009]. Based on this similarity, the CFR is expected to be a hidden dynamic and a culture loaded phenomena, that requires special effort to surface and become visible [Saffold 1988, Sorensen 2002].

It is hard to find evidence that the organization will change after something that can be identified as a paradigm shift. Orlikowski discussed a structuration model of technology that describes the organization-technology interaction. This model is based on the dual character of technology, where technology can be seen on the one hand as an external force and on the other as a socially constructed by its users [Orlikowski 1992]. The question is whether this model applies to the organisation and the technologies that are created by that organisation. That technology changes the organisation is supported by a recent publication from Zammuto et al. stating that

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organizations change under influence of factors impacting the information processing in the organization. Although Zammuto discusses the influence of IT in the organization particularly, it can be argued that adopting a new technology requires different way of processing information as well and based on this the similarity it can be expected that the organization reforms to accommodate these differences in processing [Zammuto 2007].

The concept of Collective Frame of Reference has similarities with the concept of deep structure of Gersick [Gersick 1991]. Although the deep-structure is considered to be a sub-set of the CFR; the CFR represents a more volatile dynamic, as has been shown by the patterns in Chapter 6. In this perspective the deep structure of the organization will follow a persistent CFR, but due to its intrinsic inertia it requires more time.

Santos and Eisenhardt present in their paper about the organizational boundaries concepts that seem to be related to CFR [Santos & Eisenhardt 2005]. Based on the work of Weick about sense making in organizations, Santos and Eisenhardt, state that organizational members actively participate in the collective sense making and through this sense making, information is filtered, historical interpretations and the meaning of external influences are shared, and guidance for actions is provided. Furthermore, it is noted that “sense making tends to crystallize into cognitive frames that reduce ambiguity and facilitate decision making” and “Once cognitive frames are developed, they create cognitive coherence and guide subsequent actions”. [Santos & Eisenhardt 2005, p.500]. It is apparent that cognitive frames and cognitive coherence, in relation with decision making and guiding activities, relate directly to CFR.

7.1.4 Group processes

Groupthink has a negative connotation: it is considered to be bad for a group to suffer from groupthink [Janis 1972]. The CFR results in a focused development of technology that needs to be persistent in order to provide guidance to collective problem solving. So having a strong CFR can be considered as being beneficial as it brings focus. It is recognized that a CFR that is too rigid to consider alternative options, is potentially inefficient and can be characterized as ‘groupthink’. So reversing this reasoning links Groupthink as a special case of the CFR; it is a case where the organization fails to reconsider an obsolete CFR. This is again subjective; an organization suffers from self-reference [Vos 2002] and may develop a ‘blind spot’.

This could be seen as groupthink from an external perspective, but it is questionable whether this self-referencing can be overcome. A more serious case of groupthink is if the CFR is persistently conditioned from within the organization. In the ‘Bay of Pigs’-case, which motivated Janis to develop the concept of groupthink, one of the main factors that lead to the disaster was related to the information streams to the decision makers. Deliberately obstructing information streams within an organization to keep a CFR intact is clearly a symptom of ‘groupthink’. A recent revision of the Groupthink

concept by Baron, which is known as 'Ubiquity Model of Groupthink', shows that Groupthink is less rare than what Janis suggested [Baron 2005]. Also it reduces the number of antecedents that Janis suggested to only three:

- Social identification, which represents the extent to which the group members feel connected to the group, by a common purpose, shared belief or common history.
- Salient Norms, which provides a group-polarization that influences the group decisions.
- Low Self efficacy: which results in a lack of confidence that a solution can be found.

This revision still relates to the possibility that groupthink can be a result of a CFR 'gone bad'. Without digging into the social/psychological effects of the antecedents, above, it seems appropriate that the CFR needs to be sufficiently open for new information. With a mature and open CFR a group will both be able to stay on course as well as to make reasonable decisions on when to reorient. This is similar to the notion of Amason about conflicts in decision-making process. Although studied in top-management teams, Amason found that the conflicts can improve the quality of decision-making, as long as these conflicts are functional (e.g., debate) and not dysfunctional (e.g., breakdown consensus) [Amason 1996]. As long as similar conditions are met it is expected that the creation of a CFR is possible.

Zyphur discusses a specific subject of analytical mindsets and the switching of those mindsets in order to obtain a breakthrough in organizational science [Zyphur 2009]. Zyphur defines a mindset as a routinized mode of thinking which exhibits a certain path dependency and recognizes that switching of mindset is difficult. This seems to be related to the CFR, where for example certain problem solving techniques prevail over others as they have been proven in the past and because the techniques matches the kind of problems that are associated with the current paradigm. Breaking out of this routine is part of the change in CFR that allows, e.g., to consider alternative methods.

A collective mind as described by Weick and Roberts has certain overlap with the collective reference [Weick & Roberts 1993]. However the collective mind is based on procedures to which actors conform, in order to maintain complex processes. This collective mind seems to promote heedful acting, within a predefined framework and suppresses pure individual impulsive actions. In technology development this framework is missing, but it shows that it is possible to create a situation where actions of individuals are driven by a framework.

As discussed in the previous section, Weick relates organizational collective sense making to guiding collective actions [Weick 1995]. This collective sense making leads to path dependencies similar to CFR, which seem to be confirmed by Santos and Eisenhardt, or at least within the context of organizational boundaries [Santos & Eisenhardt 2005, p. 497]. Collective sense making seems to comprise elements of CFR that were found in this study. This study contributes in the patterns of the creation and

destruction of the CFR, resembling a situation where the collective sense, makes no sense any more.

7.2 CFR in the Technology Development process

As concluded in Chapter 1 of this thesis, an in-depth description of the technology development process is lacking in literature. However, this does not mean that technology development has not been recognized as an important activity of the innovation process. Many articles describe the influence of technology on the well-being of the organization. The focus on technological change from a macro and meso-economical perspective is initiated by Schumpeter [Schumpeter 1934], making the distinction between 'circular flow' and 'economic development', which much later was identified by innovation in organization by Nelson and Winter [Nelson & Winter 1982], leading to the evolutionary economic perspective.

Dosi later linked the technological development and its path dependency of industrial blocks [Dosi 1982]. Nelson and Winter and Dosi were inspired by the work of Kuhn [Kuhn 1970], who developed a theory of scientific development based on historical analysis and introduced the notion of scientific paradigms, which govern the evolutionary scientific developments. Kuhn was influenced by the work of Polanyi, who noted parallels between scientific development and technology development [Polanyi 1962]. The work of Polanyi has led to the conclusion in this thesis that the Technology development process has many aspects that are similar to scientific discovery. Actually, the main difference is that technology development process has a different motive.

Where science is driven by gaining understanding of the phenomena around us, the motive for technology development is the creation of an artefact that can serve a function in society. This conclusion is supported by a review by Faulkner, stating that in new technological fields, like the biotechnology, the relation between Science and Technology is 'so intimate that the boundaries between them appeared to be blurred' [Faulkner 1994, p.451].

The relationship between the function of technology artefacts in society is more or less reversed in the theory from Bijker and others [Bijker 1987, Latour 1987], stating that technology is socially constructed. Garud and Rappa note that this theory ignores the actual creation of a new technology by individuals who are driven by beliefs. Howells discusses the social-cognitive aspects of innovation in a similar way [Howells 1994] and this relates to the cognitive distribution among groups that are for example involved in design [Busby 2001]. This gives rise to a model of individual technology creation and selection by society, which brings back the focus on an evolutionary perspective on technology development and associated path dependencies, similar to Kuhn's theory of scientific discovery. Indeed it is expected that technology creations in an organization are subject to influences of the society; the society or potential users of the technology

determine in the end the real value of a technology by acknowledgement of particular benefits compared to other technologies.

The orientation of the organization on its intended user group is expected to take these perceived 'social' benefits into account by accepting or rejecting a new technology [Das & Van de Ven 2000, p. 1301]. In this perspective Garud and Rappa deal with the creation of technological options, while Das and Van de Ven describe the selection of the technological options, with the notion that this selection process is subject to social influences. This still leaves open the question of whether the technology development process is different from product development. Das and Van de Ven recognize that technology forms a platform on which products are based, but leave open whether the development of products is similar to the development of technology.

Sheasley [Sheasley 1999] states that technology development is fundamentally different from product development and positioned technology development in the front end of the product development. This is not inconsistent with Das and Van de Ven's notion that the technology forms a platform on which products are based. Sheasley states that the quest for a new technology is a process discovery, which is highly intuitive and unpredictable.

A 'healthy sign' of this process are the 'ever-expanding' boundaries of the scope of the technology development program. Sheasley argues that the indefinite character of these processes is incompatible with the pragmatic business sense of investing in ventures without obtaining the certainty that something tangible comes from it. Where Sheasley identifies the generation of technological options by means of a discovery process, the selection process is less prominently discussed.

Gregory [Gregory 1995] describes the technology development by five process steps that interlink: identification, selection, acquisition, exploitation and protection. This model assumes a planned and predictable generation of new technological options as part of an identification and selection management processes.

A more recent publication about the technology development process by Cooper [Cooper 2006], states as well that technology development programs are fundamentally different from product development. Cooper states that technology development programs are rare compared to product development programs, and due to the short term focus in organizations, these programs are becoming rarer. Like Das and Van de Ven, Cooper states that technology forms a platform for product development. Just because of this positioning Cooper sees technology development as different from product development.

Boersma [Boersma 2001] made another important distinction which is related to product development and product pre-development. The activities of pre-development intend to reduce risk of the actual product development by exploring a new combination of technologies. This integrative aspect at the front-end of product development is distinct from technology development as it not necessarily involves

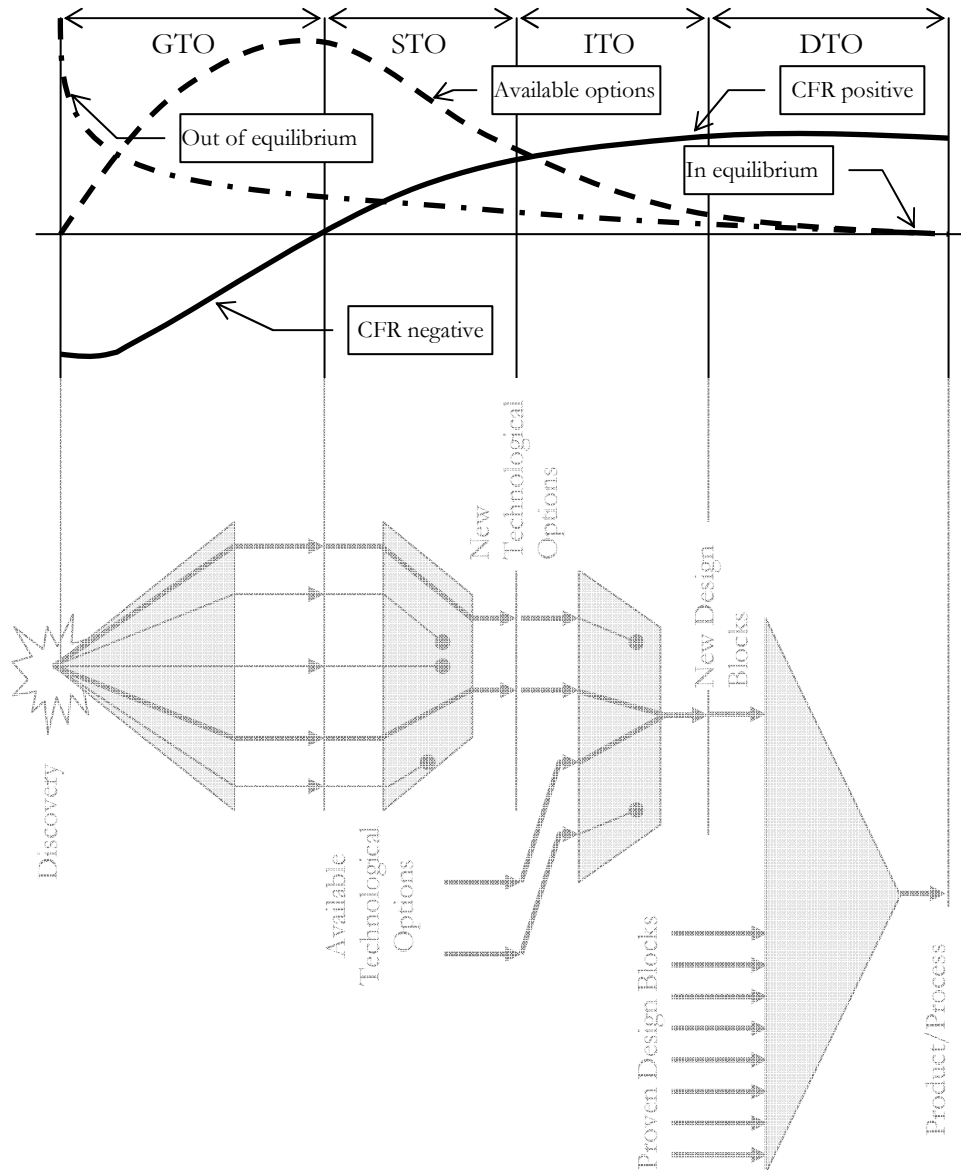


Figure 7.2: The 'TO-model' of the technological options prior to the creation of a product (faded) and a graphical representation of the CFR. In the GTO stage the CFR is absent or at least loosely present. Once selection takes place the CFR builds up and becomes more constant (mature) at the final stages in the TO model. On the same axis the available options are given. In the STO stage these options are reduced. The third graph is a representation of the equilibrium of the organization. It starts off with a punctuated phase at the start of the GTO stage, after which the equilibrium is restored.

new technologies but is related to exploring the effect and compatibility of several technical options that are required to be combined in order to obtain a new product.

The TO-model which is presented in Chapter 3 integrates the elements that are previously discussed. It takes the technology option from its discovery to the successful application into a product. The essence of the model is that a discovery leads to the generation of a technological option (GTO), once a particular function can be isolated in an artefact. This allows gaining understanding and studying the function in enough detail to 'offer' the option for further exploitation.

At the selection stage (STO) the user demands are applied to the technology options. This is the point where, according to Das and Van de Ven, the social shaping takes place. A closer analysis shows that the TO model fills the gap that Garud and Rappa pointed out that the generation of the technology cannot be explained by the theory of social construction of technology [Garud & Rappa 2001]. The TO model assumes that the Generation of Technological Options is driven by the 'unjustified belief' or CFR of the organization. On the other hand, the TO model captures the 'variation and selection' phase at the selection stage. The model does not exclude that the technology is subject to social influences that influence the selection process, but it is a process that takes place within the organization. This makes the social influences subjective; the decision making depends on the perceived 'social preferences'. This perceived social preference is part of the CFR that drives the selection process.

The CFR has different characteristics in the stages defined in the TO-model. In the GTO stage the CFR is absent, very loosely defined; the emphasis is on divergent actions with limited focus. The individuals may have a common goal state, e.g., the problem that needs to be solved, but the route towards a solution is undefined. In Figure 7.2 this phase is characterized by negative CFR (solid line), indicating there is no Collective Frame of Reference, or may be better; individuals execute actions without much coordination. Once the STO stage is entered a CFR is developed, which is indicated by a positive CFR. In the sequential stages the CFR becomes stronger, stable and more mature. The available options (dashed line) increase in the GTO stage and reduce during the STO, ITO and DTO stage. Once the product is realised, there are no options available any more; the product locked-in the technology options. Likewise, equilibrium curve (dash-dotted line) is 'out of equilibrium' in the GTO stage, while in the stage towards the lock-in of technology options, the equilibrium is restored.

The TO-model accounts for the integration phase of several technological options. This distinction connects the selection of technology to the pre-development activities as described by Boersma [Boersma 1994]. It takes into account that a product does not contain one particular new technology, but rather several technological options that are new and used. Mixing these new options with used options requires a "study" phase where the effect of the integration of these new and used options is studied. The reuse of the combination in a new cycle of product development requires activities that can be very well covered by the product development process itself; i.e., the technological

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options are optimized by the design process and offer predictable results. This process is also considered technology development, but it has clearly and evolving character; small changes and small improvements.

7.3 CFR and Path dependencies

The focus of this research is the path dependent character of technology developments at the level of the organization. In this perspective it can be seen as a subset of organizational path dependencies.

The study of path dependencies is becoming more prominent in organizational research. In Chapter 2 the work from Kuhn, Nelson & Winter and Dosi [Kuhn 1970, Nelson & Winter 1978, Dosi 1982] has been discussed, mainly because it discusses developments in scientific discovery, economics and technology along paradigms.

From the historical tradition, path dependencies in organizations have been explained by dependencies of past decisions (historical) on future decisions [Nooteboom 1997, Antonelli 1997]. Antonelli relates industrial economics to a model and concludes that path dependency can serve as a framework for industrial economics for dynamic processes like the growth and diversification of organizations, comprising the economies of scope and learning processes that result in evolutionary paths of organizations through markets, products, countries and technology. This theory does not just take historical events in account as the sole and only actor on the path dependency; it also takes into account the actors in an organization who can influence the effect of the historical event.

According to David, a local path-dependent process has three basic ingredients [David 1988]:

- A source of positive feedback that reinforces the action of agents
- Some source of fluctuations or perturbations that remain independent of the system
- Something causing the progressive diminution in the comparative strength of whatever forces are perturbing the system

These characteristics are very similar to reinforcement of the CFR as discussed in section 7.1.2, although it should be emphasized that path dependencies do not necessarily lead to groupthink.

Antonelli suggests that the most suitable theory to model these local path-dependencies is the percolation theory. This percolation methodology is based upon the basic assumption that the behaviour of each agent depends upon the decisions of his or her neighbours (see dialogue box 7.1).

An open question is still how this local influencing by the actor's neighbour and the actor takes place. An important notion is however that this stream of literature relates path dependency to the evolutionary character of the organizational processes.

That history matters in relation to path dependencies is not disputed, but a very recent publication by Sydow et al. regarding organizational path dependencies provides a broader overview of this field that recently gained prominence [Sydow 2009]. In organizational science path dependency gained more interest as it serves as a concept to explain the influence of past decisions on current decision. The basic idea is that 'history matters' and which suggests that current decisions are made in a context of imprinted history, leading to organizational inflexibility. Sydow et al. assume that path dependency is a process; something where rigidity gradually wins from flexibility. Within this process, three phases are distinguished, assuming that the process starts with singular historic events phase, then under certain conditions enters the self-

Dialogue box 7.1: Modeling path dependencies: Random Markov Chains

Organization path dependency can be described by a process where a state of an organization at a certain time t is not only dependent on the state of the organization at $t = t-1$, but also dependent on the positive (additive) and negative (subtractive) influences on the state over the time interval $[t-1, t]$. The non-linear relationship is given by the following relation:

$$X(t) = X(t-1) - (X(t-1))^2 - Z(t-(t-1)) + W(t-(t-1))$$

Where $X(t)$ is the state at time t , $X(t-1)$ is the state at time $t-1$, $Z(t-(t-1))$ is the negative feedback on state X during the interval $[t, t-1]$ and $W(t-(t-1))$ the positive feedback to the state X during interval $[t, t-1]$

This model is based on so-called random Markov Chains. A Markov chain is an interdependent relation between two states at different times. A random or local Markov chain takes into account that local influences on the state are more prominent than the overall influences of the system. These effects on the state can be of behavioral origin of actors or agents that have (limited) influence on the process and are influenced by neighbour actors or agents.

reinforced dynamics phase, which finally may lead to organizational lock-in. In Figure 7.3 a representation is given of this process.

The process of path dependency starts in an environment where many options are available for consideration but, simply because decisions need to be made in order to progress the organization, choices are made and by doing so, these choices become historic events. These historical events become actors in new decisions and therewith a dependency is created between the previous decisions. In the process, the number of options to consider becomes smaller along the trajectory of decisions. According to Sydow, the organization eventually enters a situation where the options to reconsider

are almost depleted and the range of options is limited to a band in which still alternative paths are available, but they are parallel and the variation is very limited.

With respect to technological path dependencies, especially in relation to technology change, Rosenkopf and Nerkar studied patterns in patent application of the optical disk industry [Rosenkopf & Nerkar 2001]. Rosenkopf relates path dependency to evolutionary (technology) developments, where ‘local search’ R&D activities are closely related to previous R&D activities. Based on empirical evidence, it is concluded that organizations tend to stick to local search and that “firms focus their exploration on closely related technological domains”. An important notion is that “By indulging in local search, the firm focuses on similar technology, creates incremental innovations and becomes more expert in its current domain” [Rosenkopf & Nerkar 2001, p.288]. The focus on this evolutionary development is called a “first order competence”.

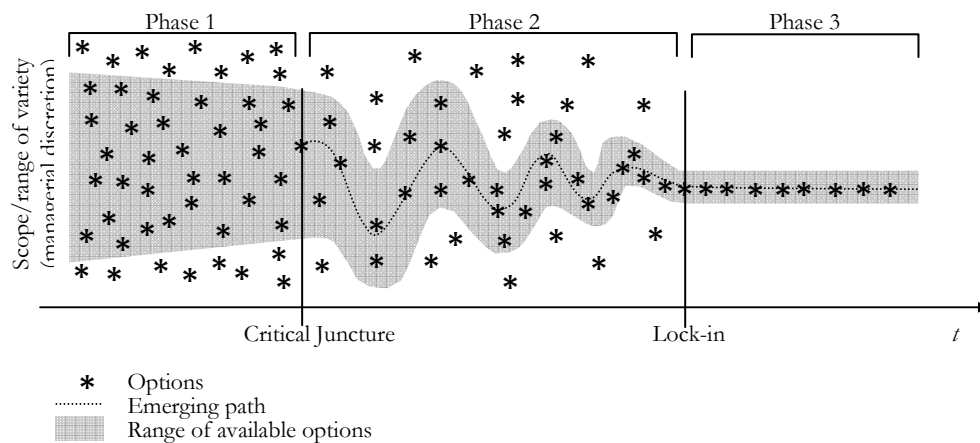


Figure 7.3: The constitution of an organizational path according to Sydow et al. [Sydow 2009]

Dougherty and Hardy and Dougherty and Heller [Dougherty & Heller 1994, Dougherty & Hardy 1996] studied innovation in older organizations and found that these organizations have difficulties in generating new products, which suggests that older organizations are more susceptible to path dependencies. Dougherty and Hardy define a new product as a product that is either intended for users that are unfamiliar with the organization or products that require new product or process technology. The latter relates to technology development in organizations and the related path dependencies.

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The main reason that mature organizations have more issues with innovation among which technology development is found to be related to what Dougherty and Hardy call “innovation-to-organization” problems. The availability of resources, processes and organizational-wide support are seen as the main innovation-to-organization problems for mature organizations, which limits the success rate of the organization. Although not explicitly mentioned it suggests indeed, that the new processes that are required to develop new technologies are hard to resource and implement within the large body of routines that constitute the operation of the organization.

The associated rigidity of the organization is related to the path dependencies described by Sydow and others. Rosenkopf & Nerkar define a so-called “second order competence” as the ability to source technologies outside the boundaries of the organization or the boundaries of technological sub units within the organization.

Garud and Rappa, also associate technological path dependencies with evolutionary technology development. In a longitudinal study towards the technological development related to cochlear implants, Garud and Rappa conclude that technology should be seen as artefacts, beliefs and evaluation routines that evolve along a certain path. In contrast with Sydow, Garud and Karnoe conclude that creating a path dependency can be beneficial as well [Garud & Karnoe 2001]. In a way this is supported by this research where path creation is thought to allow for the creation of routines that enable efficient progress along technology paradigms, which aligns well with Garud and Rappa’s findings. Also a citation in Jelinek and Schoonhoven illustrates the dualism between change and stability: Managers were actually not so concerned about ‘resistance to change’, but more concerned about ‘resistance to stability’ [Jelinek & Schoonhoven 1990, p.19].

Sarasvathy notes that goal setting in situations of uncertainty, i.e., in situations where the end-goal is not (well) defined, is not trivial [Sarasvathy 2001]. Sarasvathy states that the decision model is different for the situation where the goal is well defined and existent compared to the situation where this is not the case. The first situation is driven by causation, while the latter is driven by effectuation.

In the case of technology development it is expected that the goal state of the problem solving cycles may be well defined but not necessarily existent. Assuming that the CFR set this goal state, and that several individuals commit to this CFR in their pursuit to realize a common goal state, it is not said that this common goal is realistic. There is some difference though between problem solving to progress along a paradigm, versus a problem solving to find a new paradigm.

First of all the uncertainty about the goal state is lower when progressing along a paradigm, compared to an effort to explore beyond the existing paradigm. Secondly, the means are different; progressing along a paradigm provides means that are tailored for the type of problem solving processes. Dedicated problem solving routines are developed over time to optimize the problem solving process. This is missing for

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exploring activities; the problems are new and dedicated, optimized problem solving routines are not at hand.

In exploring problem solving attempts, available and known routines will be applied, which is basically a form of effectuation; rather than start defining and building new routines, a 'pragmatic' approach is chosen to use a combination of means at hand to make progress with the problems at end. This suggests that path dependent technology development can rely on causation, while path breaking technology development requires making use of effectuation. In this perspective the CFR is not particularly different in the two situations, while in path dependent processes the CFR sets the goal state and embodies the problem solving routines, the CFR in case of path breaking process is vanished or very weak. It could be that several individuals conform to a weak CFR, representing a common goal, the individuals basically use their own insights and methods to realize this.

7.4 Synthesis concerning CFR

In the previous sections the discussion was related to CFR and how it is embedded in literature. Based on the discussion several connecting elements surfaced, that adds an additional dimension to the results of this study. The following connecting elements will be discussed in this section

- Technology development described by the TO-model leads to passing all the stages of the path dependency process described by Sydow [Sydow 2009] and couples the CFR to these distinct processes
- CFR like phenomena come in various flavours and colours, but the main common element is the shared beliefs that apparently can drive collective efforts
- Organizations adopt new technological paradigms on regular a basis and therefore exhibit path breaking behaviour on a regular basis.
- The path breaking conditions that are formulated in Sydow 2009 and the inversed conditions to create path dependencies described in literature do support the CFR phenomena.
- Path dependency and Path breaking can be related to the state of the CFR throughout the technology development process.

7.4.1. The TO- model relates to intended path dependency

An intriguing observation is that the flow model for path developments proposed by Sydow [Sydow 2009] has large similarities with the TO model that has been proposed in Chapter 3. The similarities are not only in shape but also in concept (see Figure 7.3).

The first phase of Sydow's model, the Pre-formation phase is characterized by a broad scope of action. In this phase the effect of the decision is unpredictable. Compared to the STO stage this is very similar; in this stage there are various options available and the actual value is uncertain.

In this stage, the dominant process is the process of problem solving and once a breakthrough has been realized, i.e., a combination has been found that provides the desired functionality; the researchers start to focus on this technology option and the options in its vicinity. In analogy with Sydow's the process enters a critical junction; the search path of problem solving narrows and in a figurative interpretation, one can say that the spherical search space changes to an ellipsoidal search space with the long axis of the ellipsoid aligned with a distinct search direction (see Figure 7.4).

Once passed the STO stage, the sequential ITO and DTO stage, leads to a further limiting of the search space and the number of options to be considered are further reduced. This is very similar to the process described by Sydow after the critical junction. In this phase of the path dependency process so-called self-reinforced dynamics start to take over. The background of this self-reinforcing is thought to be in the concept of increasing returns [Arthur 1989]. The concept of increasing returns represents a positive feedback process, where the optimization of a particular variable leads to increasing benefits.

This eventually leads to a set of preferred variables leading to a set of dominant solutions. This is very similar to the problem solving process that takes place in the technology development process; researchers try to realize certain goals by varying

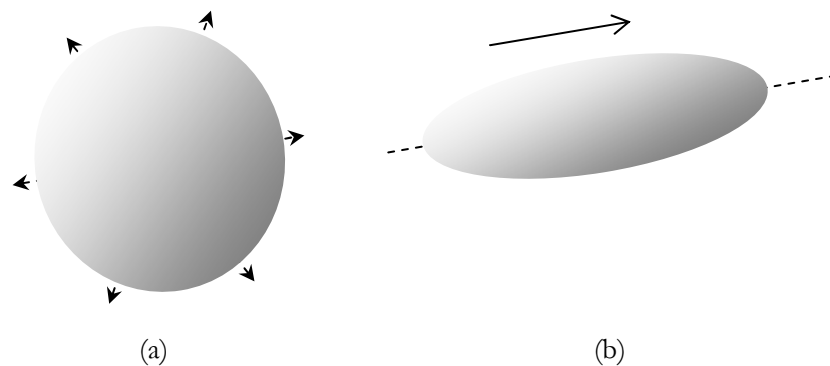


Figure 7.4: A representation of the search space as at the start (a) and the end (b) of the STO stage. Initially the researchers will explore the options in a spherical fashion and there is basically no sense of direction. Moving on, the process of variation and selection provides a breakthrough; the research efforts are focused on a certain direction and the search space becomes ellipsoidal, and progresses along a long axis of the ellipsoid.

variables in the hope that a positive correlation between the variables and the goal state is found. Once this is found, the researchers will try to optimize this variable in such a way that the assorted effect is most beneficial. These iterative processes will carry on till the solution is 'good enough'; meaning that the goal state is reached or sufficiently approached to be meaningful.

Once all the goals are sufficiently met, the found option is becoming part of a product and so-called lock-in takes place. In case of technology development the technology becomes an integral part of the product. Depending on the dynamics of the market, the technology option tends to stick to the product for a longer time, serving as a platform for several product generations [Das & Van de Ven]. Consequently the problem solving cycles recommence where it was stopped in the previous product generation; the option is further optimized by setting a more challenging goal state. In general the steps of improvement become smaller during the sequential iterations and at this stage

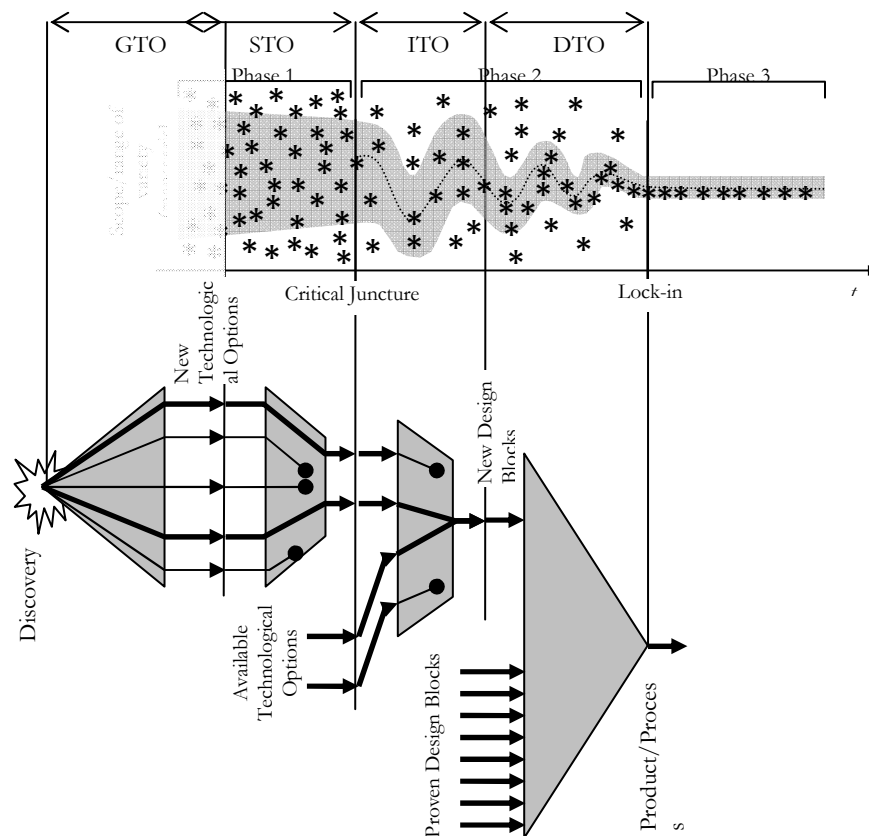


Figure 7.5: The TO model in comparison with the path dependency model of Sydow [Sydow 2009]. The critical junction takes place in the after the Selection of Technological Options stage, while lock-in occurs after the release of the product.

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the progress can be characterized as evolutionary.

In conclusion it can be said that passing through the technology development stage as presented in the TO-model results in a path dependency. Important to note is that this path dependency is intended and required in order to select and deploy a technological option into a product. It also shows that once the technological option is incorporated in the product, it is locked-in and develops in an evolutionary fashion; small improvements at sequential iterations (see Figure 7.5).

7.4.2 The commonality of path breaking processes in organizations

In the path dependency literature, path breaking is seen as a very rare occurrence. A stream within this literature even claims that an organization cannot break with its path and is basically doomed to walk it all the way till it hits a dead end. This research has shown that path breaking behaviour takes place in organizations, at least concerning technology developments.

Although technology development is one of many processes in the organization, it is argued that a technology change within a Technology Intensive Organization has an impact on many other processes as well. It is recognized however that not every technology change in the organization has large impact; it varies by the amount of impact on other organizational processes. Some technology changes propagate throughout the organization or even across organizations, while others are confined to a department or even a sub department.

In the previous section it was shown that technology development creates path dependency within an organization. Consequently, introducing a new technology option in a product requires a path breaking process, resulting in activities that are different from previous practices. It is argued that this process is taking place on a regular basis and that therefore path breaking processes take place in organizations on a regular basis and may be much more common than suggested by current literature.

7.4.3 The flavours and colours of the Collective Frame of Reference

The CFR is defined in Chapter 5 as 'shared unjustified belief' which positions CFR as 'subjective knowledge'. Knowledge is, by definition, not subjective in the sense that knowledge should be verified against references that are value free. Knowledge is not absolute either as it is impossible to verify in an absolute manner. This forms the background of the softer definition of knowledge as 'justified belief', which basically 'keeps the door open' for evidence that the beliefs are incorrect, but were justified at present time and circumstances.

The question remains, what constitutes to beliefs, especially in the context of the CFR. Identifying CFR with beliefs is not sufficient to explain the driving force of the CFR, it

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is about what constitutes to that belief. Beliefs are in general not direct and explicit; it is rather the implicit and circumstantial effects that constitute to a belief. In literature these implicit effects are widely reported and discussed. Most likely because these effects are hard to grasp, the spectrum of nomenclature is very broad, ranging from emotions, to groupthink, to selective perceptions, blind spots, organizational memory, etc. The common notion is however that:

- A (cognitive) frame or frame of reference can be shared among organization members.
- A shared (cognitive) frame or frame of reference results in coordinated action of the group members.
- A shared (cognitive) frame or frame of reference induces path-dependencies.
- A shared (cognitive) frame or frame of reference constitutes from beliefs, emotions, and psychological and social influences.

From the results and analysis of the literature the following conclusions concerning Collective Frame of Reference are obtained by synthesis:

- CFR is socially constructed; this implies that the goal state of the problem solving process, which is induced by the CFR, is socially constructed as well. This seems related to the Social Construction of Technology (SCOT) theory. Although it is recognized that this theory refers to the society and its influence on acceptance or rejection of technologies, it is assumed that a pre-selection of technologies takes place within organizations based on a perceived acceptance pattern of the society. This perception is part of the CFR and therewith influences the selection of technological options as part of the technology development process. This carries some logic as firms try to anticipate how their products and associated technology based functionality are received in the society (or market), and it can be assumed that firms have a perception about this acceptance or rejection [see e.g. Borgatti & Foster 2003, Munir & Jones 2004].
- The notion that technology development leads to path dependence on the one hand and that CFR drives technology development, leads to the conclusion that CFR leads to path dependency. This became apparent in the observations in the field and is confirmed by several sources in literature [e.g. Sydow 2009, Nooteboom 2007]. Also resulting from the observations is that a destruction of the initial CFR and the recreation of a CFR around a new path shows that the creation of CFR is a driver for path dependency, while the destruction of CFR allows for path-breaking or a paradigm shift. The apparent direct relationship of CFR in relation to path breaking or paradigm shift is not mentioned explicitly in literature.
- The path dependency is not limited to the operational level - path dependencies in the management teams have been observed [Beckman &

Burton 2008]. The idea that a managerial CFR can be distinguished would relate this path dependency to this managerial CFR, very similar to the operational CFR relating to path dependency at the operational level.

7.4.4 Path breaking conditions (PBC) in relation to the CFR

In this study the creation and destruction of the CFR has been found to be a factor for technology change in the organization. In this perspective, the CFR should be connected to the breaking of organizational path dependencies. Sydow states that path breaking can be realized by interrupting the self-reinforced processes, and considers the following drivers; reflection, understanding, emotional aspects, cost of effort, willingness to accept new rules, management influences. Below a comparison is given of the path breaking conditions, indicated by PBC, and the dynamics of the CFR that have been observed in this study.

PBC: Path breaking starts with reflection; shifting the attention from the operational mode (along the path), to an observing mode which is a necessary condition to observe the self-reinforced dynamics. The reflection on self-reinforced dynamics is hampered by the fact that the self-reinforced dynamics are often hidden. Reflection is hampered by emotional barriers; an emotional attachment to the organization hampers reflection and therewith the ability to critically observe the self-reinforced processes in the organization. Another reflection hampering mechanisms are regimes that prevent self-reflections; organizations can exhibit so-called closing behaviour, caused by self-reinforced patterns that exclude self-reflection.

CFR: Path breaking starts with non-conforming behaviour; an individual develops an unjustified belief that is not longer aligned with the Collective Frame of Reference. This is a process that takes place continuously, but the effect on the organization is highly dependent on the propagation of this alternative CFR in the organization. This initial unjustified belief is 'filtered' and judged on its merits by other individuals, who may reject or adopt the unjustified belief.

PBC: The emphasis is on 'restoring choice', depending on the character of the self-reinforced process, the reversibility and the possibility to create a new advantageous situation. Learning effects are reversible, but it comes with a high cost; the learning effects are acquired within the context of the path, and migrating to a new path requires additional efforts to obtain learning effects related to the new path. For self-reinforced processes like coordination effects the willingness to move to a new path is related to the preparedness of the organization to adopt a new regime of rules.

CFR: The alternative CFR propagation process is dependent on the state of the organization and is susceptible to not only organizational factors, organization self esteem, culture, performance, but also to individual factors like individual unjustified

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beliefs, political agendas, likes and dislikes. All these factors filter the alternative CFR and determine whether it holds or fades out. Once an alternative CFR holds, the organization will eventually deploy activities to bring the organization to the new path. Knowledge and routines that are related to the current path may not be relevant to the new path. This requires the build-up of new knowledge that is relevant for the new path. New routines emerge that allow efficient operations on the new path.

Liyanage and Barnard describe actual technology paradigm shifts and argue that these transitions are possible if the knowledge distance and the absorptive capacity of the transition process is sufficient [Liyanage & Barnard 2003]. The knowledge distance is determined by the prior knowledge of the organisation and the required new knowledge associated with the technology paradigm shift. Related is the absorptive capacity of the organization, which determines the ability of the organization to assimilate to new knowledge [Cohen & Levinthal 1990].

In the context of a paradigm shift, the absorptive capacity can be associated with the ability to recognize that a specific paradigm is useful to consider in order deal with the crisis that was imposed by the inability of the current paradigm. One could say that the decision of looking for alternative paradigms is an expression of absorptive capacity, as it is based on the understanding that a new technology is required.

In summary, the results of a literature study in four main streams reveals concepts with similar elements to the Collective Frame of Reference. These elements are rather scattered, not well defined and unstructured. By adopting the concept of Collective Frame of Reference, and its assumed role in change processes, it is expected that more structure can be brought into the study of technological change in organizations or organizational change in general. The connections that have been found to path dependency and the punctuated equilibrium theory, may contribute to a better understanding of path dependency and, may be more important the breaking of path dependencies.

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“It’s no wonder that innovation is so difficult for established firms. They employ highly capable people... and then set them to work within processes and business models that doom them to failure”¹⁹

Chapter 8: Towards Managing the Collective Frame of Reference

This Chapter describes the management implications of the Collective Frame of Reference as a driving force behind technology development. In order to put these implications into perspective, a wider description of technology development management is provided. The management processes described in this Chapter should be seen as a typical practice, which can be generalized for a typical Technology Intensive Organization. This Chapter gives an overview of how several technology management processes are interacting towards the creation of a new technology in the organization. The Chapter will include recommendations to manage the Collective Frame of References for different stages of the technology development process in Technology Intensive Organizations.

8.1 Motivation for Technology Development

The motivation for introducing new technologies to a TIO has several origins. The first and foremost motivation is to ‘fuel the product development engine’ [Phaal 2001, Das & Van de Ven 2000, Cooper 2006, Rosenkopf & Nerkar 2001, Sheasley 1999]. A TIO developing products for certain markets has a strong motivation to maintain this market, especially if this market is profitable and offers future potential to remain profitable. The products that are developed for this market should keep pace with the user requirements and the competing offerings and sooner or later this requires new technologies [Dougherty 1996, Nevens 1990, Wheelwright & Clark 1992]. Often a TIO serves several markets that differ in characteristics and in maturity. These different markets change over time, which itself imposes changes in requirements of the successive products. For example, one of the characteristics of a maturing market is that cost becomes a more prominent factor. This changing requirement requires products based on more cost effective technologies [Dosi 1988, p.1162, Gort & Klepper 1982]. A TIO is not always capable or willing to follow those market developments all the way to the end. Some TIOs will focus their strategy on the early years of a new market where performance is more important and cost less of an issue, resulting in good margins but generally with lower volumes. The main condition here is that the TIO has a technology base that can provide this high-end performance and can deal with competing offerings.

At a certain point in time the emphasis on performance is less pronounced as the performance requirement is settled, and, e.g., lower cost becomes more prominent especially if the market grows in volume [e.g. Mohr 2005, p.300]. For a TIO this

¹⁹ Clayton Christensen & Michael Overdorf [Christensen & Overdorf 2000]

development can result in a gap in the technological and other capabilities and may require a strategic decision; either invest in lower cost technologies and capabilities to move along the 'cost-down' paradigm, or abandon the market and find new(er) markets that follow the 'high performance' paradigm and where the current technology base is relevant. Fair to say is that this approach is not described as a strategy, but is often referred to as a failure of an early mover [e.g. Golder & Tellis 1993].

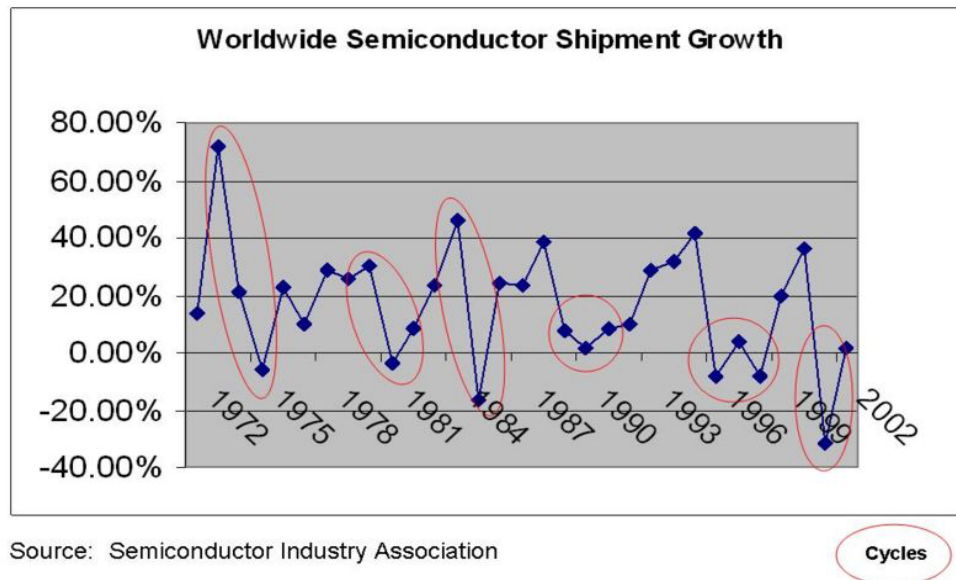


Figure 8.1: The fluctuation of the semiconductor markets in terms of shipment increase and decrease. Organizations supplying this industry will experience similar fluctuations in their product revenues.

Although it is recognized that operating in a large volume markets can be beneficial; the notion here is that an organization has not necessarily the capabilities to follow the market towards a high volume, low cost paradigm, and rather takes the benefits of high margins in earlier stages of the market development.

Therefore, it is not only the technology base that determines the best approach; the capabilities, routines and also the CFR of the organization determines the best fit for the TIO in relation to a market and its development.

A second reason to develop new technologies is entering a new market. In general an organization will strive not only for continuity in the longer term, but also for stability in terms of performance and growth. An organization with highly fluctuating revenues is less valued by the current and potential stake/stock holders and this limits the ability to obtain financial resources for investments. Also investors tend to benchmark

organizations on metrics that reflect how successful new product introductions are [e.g., McClure 2003]²⁰.

The stability of the organization is related to the fluctuations of the markets that are served by the organization. For example, the semiconductor market is known for relatively large fluctuations over time (see Figure 8.1), where the shipment of products increase and decrease with a double digit percentage. An organization supplying to the semiconductor industry will ‘feel’ these fluctuations and the revenue over time will fluctuate likewise.

One of the practises to obtain more stability for the organization is to find markets that show less fluctuations and, more importantly, have fluctuations that are ‘out of phase’ with fluctuations in the other served markets. An organization built on several of these market-pillars will provide more stability and is more robust to weather significant downfall in one or more of the serving markets. Developing one or more of these market pillars may require different technologies and capabilities than what is available within the organization. The development of a new market pillar forms a motivation to obtain access to technologies that are not necessarily supporting the current product developments.

A third motivation to develop new technologies is risk mitigation. In dynamic market areas, where competitive technologies are a very prominent factor, an organization can decide to develop alternative technologies in order to mitigate the risk of not having access to the winning technology (see dialog box 8.1). Also in situations where multiple concepts can be chosen as a standard, it is a viable strategy to obtain access to multiple technologies in order to be able to support the winning standard.

8.2 Technology planning

Technology Intensive Organizations develop products or services that are highly dependent on technology. As discussed previously, at best the Technology portfolio needs to be maintained by evolutionary developments. In some cases the TIO is forced to take more radical steps and change the technology paradigm (see, e.g., Chapter 3, 4). Whether the development is evolutionary or radical, it requires funding and planning. The planning and funding may depend on the type of technology development.

²⁰ One way to perceive the proficiency of R&D is to calculate the percentage of sales that come from products introduced over a period of time, say the preceding three years. For the calculation, investors need annual sales information for specific new products. If lucky enough to get that kind of data from company reports, investors can do the calculation this way: $\text{New Product Sales (previous three years)} / \text{Total Sales (previous three years)} = \text{R\&D Output}$ The resulting percentage gives investors a sense of R&D success as well as R&D output and offers a useful metric for comparing R&D performance with peer companies. [McClure 2003]

In Table 8.1 the seven types of technology developments have been categorized. These categories flow down from the TO model presented in Chapter 3, and the notion that evolutionary developments move along an existing technology paradigm, while radical developments happen along a new paradigm. The latter assumes that the organization has to generate knowledge and capabilities in order to bring this new technology to deployment in a new product.

Dialogue box: 8.1: Lithographic technologies beyond the optical wavelengths

Lithographic equipment for the Integrated Circuit (IC) industry is used to apply patterns on a silicon substrate (wafer). These patterns in combination with IC processing steps form IC devices, e.g., transistors on the wafer. There is a down scaling trend in the IC industry, which is also known as Moore's law, which drives towards new generations of process capabilities that are capable of producing smaller IC devices. The lithographic process is a very prominent factor in this downsizing as the dimensions of the device are mainly determined by the minimum dimensions that can be patterned on the substrate. The lithographic equipment manufacturers are entering a technological barrier, where the patterns cannot be projected with optical wavelengths and the patterning concept needed to change radically in order to provide the smaller patterns. There are at least four technologies that can provide smaller dimensions; Extreme Ultra Violet (EUV) lithography, Electron Beam (EB) lithography, Ion-Beam (IB) lithography and Soft X-Ray (SXR) lithography. The two photon based concepts, EUV and SXR require 'optics without lenses', meaning that the wavelengths of the photons are too short to be projected by optical lenses. The other two concepts are based on particles (electrons, ions), which can only be projected by electro magnetic manipulators.

The lithographic equipment manufacturer ASML used the strategy to participate at a certain time on with several technology development consortiums that pushed these technologies forward. As ASML was dependent on the outcome of several developments, it chose to participate and invest in the most promising technologies in order to secure access to the prevailed technology. From 2001 onwards the main focus is on the EUV technology and ASML is currently working towards EUV based products.

The developments are categorized according to four determining factors:

- Existing and known physical phenomenon that underlies the technology vs. new and unknown physical phenomenon that underlies the technology: the technology development of the switching mirror, described in Chapter 4 is an example of an unknown, new physical phenomenon that needed to be explored first in order to develop a technological artefact or device.
- Existing application of the technology vs. new application of the technology: a technology that is firstly applied by the organization, the organization requires time and effort to explore the use the technology in a particular application.

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- Existing combination of technologies vs. new combination of technologies: like a newly applied technology, a new combination of technologies requires time and effort to explore the effect of the combined technologies.
- Existing technological parameters vs. new technological parameters: these parameters are basically design parameters that are in general part of a common product development process. In some cases the required parameters are beyond the intrinsic capability of the technology or are only achievable by a large effort. This is a typical case where an organization considers a technological paradigm shift, resulting in a either a new combination of technologies, or a new primary technology.

In Table 8.1 the effect of the combination of the four factors is given for the following seven characteristics:

- Revolutionary or Evolutionary Technology development: this characteristic basically relates the impact of the change to the organization or parts of the organization. A revolutionary development requires the generation of knowledge within the organization or parts of the organization which moves beyond the current routines that are practised in the organization.
- Planning of the development process: based on the impact on the organization the development process has to be planned in accordance with a successful product development process. In general the organization has to accommodate knowledge generation processes separate from the product development process, although in cases where the technology can be 'tweaked' to obtain the required product requirements, the effort is seen as part of the design process and can be accommodated within the product (pre) development process.
- Timing and duration of the process: although it is difficult to discuss the specific duration of the technology development process steps, a qualitative measure relative to the product development is given here. Depending on the impact on the organization and the amount of required knowledge, additional technology development steps are executed in the front-end of the product development. A product pre-development stage is expected to range within 0.5-1 times the actual product development phase, while a more fundamental technology development process is expected to last 2-5 times the product development process.
- The motivation for the technology development: the motivation ranges from incremental product development, which is typically included in the product development process to innovative Product development to revolutionary product development, depending on the impact of the technological change on the product performance or better, perceived performance. In some cases the technology development aligns with the development of a new market.

	Technology development factors	Innovation type	Development type	Timing/Duration	Motivation	Funding
A	Existing Phenomena Existing Applications Existing Combinations New Parameters	Evolution	Incorporated in Product development	Within product development/ product development duration	Incremental Product development	Funded within the product development program
B	Existing Phenomena Existing Application New Combinations New Parameters	Evolution/ Revolution	Pre product development	Prior to product development/ 0.5-1 times the product development duration	Incremental Product development	Funded as an feasibility phase prior to the product development program
C	Existing Phenomena New Application Existing Combination New Parameters	Evolution/ Revolution	Pre product development	Prior to product development/ 0.5-1 times the product development duration	Incremental Product development	Funded as an feasibility phase prior to the product development program
D	Existing Phenomena New Application New Combination New Parameters	Revolution	Pre product development	Prior to product development/ 1 to 2 times the product development duration	Revolutionary Product Development	Funded by product development program
E	New Phenomena Existing Application Existing Combination New Parameters	Evolution/ Revolution	Technology development	Prior to product development/ 2-5 times the product development duration	Innovative Product development	Funded separately by Fundamental Research budget
F	New Phenomena Existing Application New Combination New parameters	Revolution	Technology development	Prior to product development/ 2-5 times the product development duration	Revolutionary Product Development	Funded separately by Fundamental Research budget
G	New Phenomena New Application New Combination New Parameters	Revolution	Technology development	Prior to product development/ 2-5 times the product development duration	Revolutionary Product Development /New Market Development	Funded separately by Fundamental Research budget

Table 8.1: Seven different types of technology development, characterised by type of innovation, type of development, timing and duration, motivation and type of funding

Chapter 8: Towards Managing CFR

- The funding of the product development; the technology developments that are executed within or in close conjunction with the product development process are typically funded by means of a product development budget. This budget is in a way coupled to the market expectations of the new product. Although product pre-development is a different activity than product development, it is often coupled as product pre-development is seen as risk mitigation for the actual product development.

More fundamental technology development is less directly coupled and is commonly funded separately. Although new technology ventures are initially financed by venture capitalists [Mohr 2005, p.71-73] that are used to financial undertakings that have a 10-20% success ratio, an organization typically has to consider similar odds for these more fundamental technology developments. Technology Intensive Organizations tend to report the R&D spending as a percentage of the revenue. This percentage is in the order of 15% to 30% depending on the maturity of the markets and size of the organization. These funds are in general subdivided in product development budgets, pre-product development budgets and fundamental research budgets.

Technology evolves over time by further technology developments which need to be maintained in order to provide improved product generation. As a result of sequential and successive product development cycles, the products are planned in time in such a fashion that the revenue streams generated by these products is sustainable [Imai 1985, Rosenberg 1992, p.233]. Based on the market demand, competition and other variables, an organization estimate the life cycle of the product in order to plan the introduction of successive products (see Figure 8.2). In doing so an organization is able to maintain the revenue level constant as the declining revenues of the current product are compensated by the revenues of the new product [e.g. Dickinson 2001].

This is very similar as a platform approach; an organization following a technology paradigm and serves a certain market, creates inherently a technology platform, very similar to the notions of product platforms. Therefore it is expected that some of the considerations and decision that are valid for product platforms apply to technology selections as well [e.g. Halman 2003]. In order to maintain this cycle of successive products, the organization needs to obtain access to technologies that can provide the required product value for every new product.

On a somewhat larger scale Balachandra et al. proposed a Double Helix Model that describes the evolutionary development of technologies, which intertwines with the development of the application areas. He describes for example the development of the computer processors in relation to the development of the computer market, starting at large main frames storing data at a corporate level towards the personal computer, providing individual productivity [Balachandra 2004].

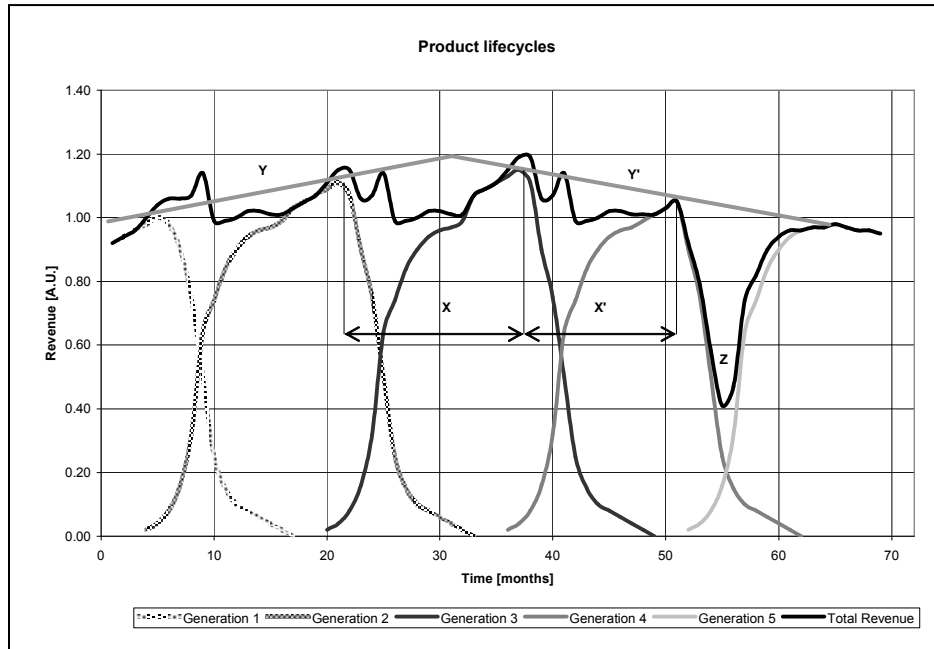


Figure 8.2: The Product Life Cycles of five sequential product generations and the total revenues that is generated by the product line. Preferably an organization tries to plan the successive product generations in such a fashion that the revenues remain constant. An increasing or decreasing demand can drive the revenue up (Y) or down (Y'). If the product lifecycle reduces (X') compared to the previous cycle time (X), a relatively sharp decrease in the revenue occurs (Z).

Many organizations generate product roadmaps or similar forms of new product plans, describing the successive products within a forward looking window of several years. Based on the predicted function requirements a technology roadmap can be created which shows the required technologies to support the sequence of future products (see Figure 8.3). On the technology roadmap three types of entries can be distinguished:

- Direct coupled: Here the technology feeds directly into the product and the development of this mainstream technology is kept in pace with the required functionality of the product roadmap entry.
- Alternative coupled: This is a technology that is developed in parallel to the mainstream technologies. The functionality of this technology is very similar to the mainstream technology and therefore it can be exploited as an alternative. At a certain point in time, product developers can select either the mainstream technology or the alternative technology. This approach allows for risk mitigation, for example if there is uncertainty about which of two technological concepts will become an industry standard.

- Future coupled: This technology has no direct link to the product line, but the organization expects that the technology offers sufficient future potential to be exploited. This type of technology development allows the organization to prepare for a future paradigm shift, as it starts to develop a knowledge base long before a shift is imminent. The benefit to start early with exploiting future applied technology is offset by the uncertainty concerning the outcome and future gains. The chance to work on the prevailing technology in the future is low but success is very rewarding.

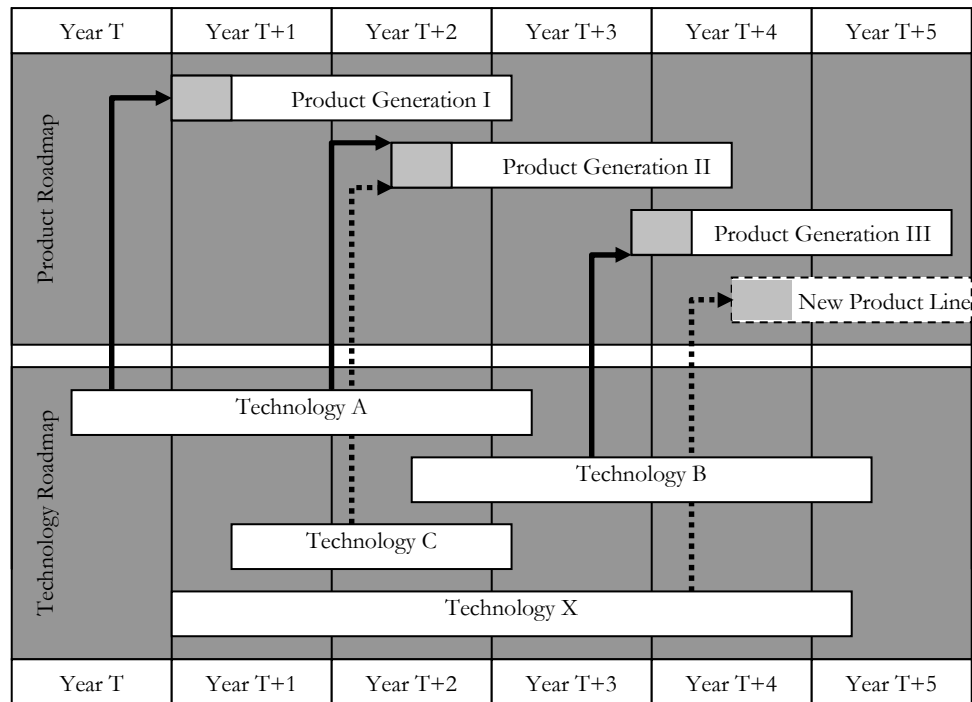


Figure 8.3: A combined technology and product roadmap. After establishing the product roadmap, the technology roadmap can be created based on the functional requirements of the sequential products. The technology roadmap may contain alternative technologies (C) and technologies that support future, not fully defined product lines (X).

An organization has to balance the development efforts over the three categories in order to obtain a technology portfolio that provides solutions for upcoming challenges. From practise it is proven that spending R&D resources on the Future coupled category is troublesome [Cooper 2006]. The uncertainty is high and the benefits in time

lie typically beyond the operational horizon. However, investing some percentage of the Technology development budget on this category is expected to be beneficial, not only because of the increased chance to have access to an future exploitable technology, but also because of the increased exploitable knowledge level in the organization, which is expected to provide benefits in general, as it brings variation into the organization.

Although it may require more research to accurately generalize, a 60%/30%/10% division between resources for Direct coupled, Alternative coupled and Future coupled has been observed for several Technology Intensive Organizations. Although this coupling does not directly relate to so-called basic research, applied research and development, it is expected that the components of applied and basic research are predominantly executed in alternative and future coupled technology developments. The ratio between spending on basic research, applied research and development of the US industry, has been studied by the US Congress Budget Office [CBO 2007], and has been found to 5% for basic research, 16% for applied research and 79% on development.

8.3 Technology portfolio management

The essence of technology management is to maintain a technology portfolio that is sufficient to serve the spectrum of products that the organization deploys in various markets and to give the organization access to new attractive markets if desired [e.g., Dickinson 2001]. In a broader perspective Bewonder gives an overview of the elements which should be contained in Technology Management: identify new opportunities, sharpen the knowledge creation process, manage knowledge evolution, protect accumulated knowledge, improve productivity of knowledge workers, scan competitors trajectories reducing the new product realization cycle and evolve cognitive knowledge in the form of technology foresight [Bewonder 2000, p.55].

This broad description of technology management shows that technology management can be identified as knowledge management. Maintaining a sufficient technology portfolio includes both evolutionary and revolutionary technological developments, which need to be executed timely and within an affordable budget. In the following sections particular aspects of technology management within the context of this research are discussed in detail.

Adopting the notion that technology development takes place along paradigms, the essence of technology management becomes managing the decision process of either developing technology along an existing paradigm or exploring a new paradigm. One approach is not necessarily better than the other; an organization continuously jumping to new paradigms is inefficient and is wasting resources as it does not allow for exploiting the technology base by developing and marketing products along a paradigm.

Also, allowing the organization to learn and create routines allows for more efficient developments and operations which increase the strength of the competitive position. In contrast to this, an organization that sticks to a paradigm too long ends up in a situation where the existing paradigms reaches a 'dead end', which jeopardizes product developments for the served markets. Almost by definition organizations tend to stick to their paradigms as they provides a framework for better predictability, planning and perceived low risk [CBO 2007, p10, Christensen 2000, p.5]. A paradigm shift exposes the organization to uncertainty, higher perceived risks. Moreover the organization's routines and resources will be revalued in perspective to the new paradigm which leads to organizational change and the induced resistance to change.

Consequently, technology management implies that these change processes should be initiated, managed and executed [Christensen 2000, Christenson 2002]. The implications of the change process are significant; a new technology may require new manufacturing capabilities, new supplier networks, and different human resources. This imposes a large workload on the organization especially as these processes often take place in parallel to operations that are based on the old paradigm in order to prevent discontinuities.

Given the consequences for the organization, one of the key questions related to technology management is when an organization should leave the existing path or paradigm and start a change process to implement a new technology.

8.4 Description of the technology paradigm shift process

In the innovation literature a distinction is made between sustaining and disruptive innovation [Christensen & Overdorf 2000, Adner 2002]. Sustainable innovation is defined by evolutionary development that make a product that is already valued by its users perform better, while disruptive innovation create a entirely new market [Christensen 1997, Christensen & Overdorf 2002 p.71]. Although a 'new-to-the-organization' technology not necessarily leads to an entirely new market, many of the organizational issues of disruptive innovation apply to introducing a new technology in an organization. The introduction of a new technology can have a large impact on the organization and it requires forward planning, often beyond the 'normal' business cycle. Not only does the technology development process needs to be managed, but also the implementation, which may require significant change of the current organization and operations.

Typically, the organization will shift to a new technology paradigm in three phases; the technology orientation phase, the technology decision phase and the technology implementation phase (see Figure 7.4). This paradigm shift process is considered to be very similar to the Kuhn's scientific paradigm shift process that is described in Chapter 2 [Kuhn 1970].

Collective Frame of Reference in Technology Developments

As with a scientific paradigm, an organization is in analogy with the scientific community following a current paradigm. While the scientific community will carry on along this paradigm until an undeniable crisis appears that makes the current paradigm obsolete, an organization can enter a similar state where the current paradigm evidently leads to decline. As with scientific paradigms shift a search for new paradigms starts where several options are considered to solve the crisis. Analogous

Analogue to this scientific reorientation, in the orientation phase the organization performs a '360 degree' orientation on alternative technology paradigms that show potential to offer a solution to an anticipated 'roadblock' with the current paradigm. It implies that the organization foresees or experiences limitations of the current paradigm. In the orientation phase alternative paradigms are explored and as much as possible information is collected, which is used to benchmark several alternatives. In some cases the available information is sparse and insufficient to make a decision. This may lead to feasibility studies that are positioned along several paradigms, which

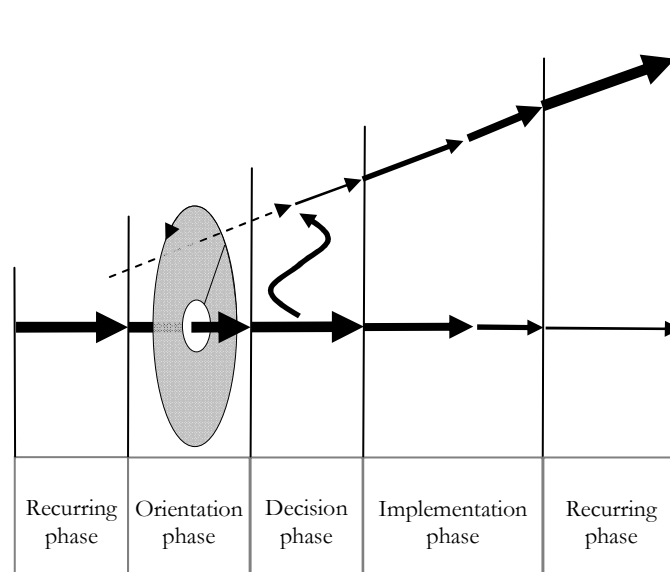


Figure 8.4: The paradigm shift process in an organization. The process starts from a recurring phase where the existing paradigm rules, and which is supported by an existing CFR. After the existing CFR starts to deteriorate the organization is entering a phase of orientation, in which other paradigms are considered. In the decision phase, the organization decides to follow a new paradigm. Once this decision is made the organization starts to implement the new paradigm, supported by newly formed CFR. After the implementation, the CFR is reestablished and the organization enters a recurring phase along the new paradigm.

implies that the organization generates knowledge of multiple paradigms before it is able to decide on a particular paradigm (see also dialogue box 7.1). It implies that the reorientation phase should provide sufficient knowledge of the alternative paradigms to make an informed decision; i.e., with some level of certainty a theoretical or physical concept should be available from which it can be deduced that the anticipated barrier can be taken down or bypassed.

This is different from a scientific paradigm shift as there is no decision process associated with following a new paradigm; a new scientific paradigm is accepted as it overcomes earlier faced anomalies and provides a knowledge base that is consistent with experimental data.

The decision phase is very similar to other decision processes in the organization, although the impact of the decisions can be substantial and the consequences cannot be fully anticipated. Along the sequence of developing the technology, incorporating it into a product and developing/educating the market, all within the right window of opportunity, many obstacles may occur. This is also reflected in the success rate of 10-20% for introducing a new technology [e.g. FETC 1997]. It is most likely a utopianism to expect that all these factors can be determined in a single decision process, especially as many factors are outside the influence sphere of the organization. Therefore it is assumed that the decision process looks very much like a convergent funnel as described by Wheelwright and Clark [Wheelwright & Clark 1992, p.112], and also the STO stage in the TO model presented in Chapter 3.

The technology development forms the front-end of the technology implementation phase, and represents the first steps along the new paradigm. It does not lead directly to new products but the organization starts to obtain experience with the new paradigm and gains understanding of how to apply the new technology; the organization learns and builds a knowledge base. Eventually, if the technology has become mature enough, it will be implemented in a product and offered to the market.

8.5 Managing Technology Paradigm shifts

The analysis described in the previous chapters relates to the punctuated equilibrium process [Pettigrew 1985, Gersick 1991] to paradigm shifts. In equilibrium an organization focuses on following the existing technology paradigm and develops technology by executing recurring problem solving cycles that follow a reasonably well-defined pattern. These periods are punctuated by periods of radical change; the organization decides to leave the existing technology paradigm and enters a phase of (re-)orientation, resulting eventually in following a new paradigm, bringing the organization again into an equilibrium state where efficient, routine driven technology development can take place.

Collective Frame of Reference in Technology Developments

The Collective Frame of Reference (CFR) plays a role in the transition of this equilibrium-to-punctuated and vice versa. The CFR drives the shift from the focus on the existing technology paradigm to the reorientation on the new technology paradigm and once this shift has been realized the CFR drives the focus back on the progressing along the new technology paradigm in recurring cycles.

The typologies that are defined in Chapter 5 are relevant for the CFR throughout phases of the paradigm shift. In the recurring phase the organization operates in a type 3 CFR as can be expected from an organization following a certain path. In the reorientation phase the CFR deteriorate and becomes very weak and may result in a type 1 CFR were the organization is in agreement on the fact that a change is required. During the reorientation phase the search for new paths can become more focused and a type 2 CFR can be established where there is an agreement of the goal state. Once the new path is found the organization reenters a recurring stage where a type 3 CFR is established.

This ability to drive the organization to focus, reorientation and focus again, suggest in their turn that managing the development of CFRs is instrumental to managing technology paradigm shifts. The following will give five more specific suggestions for managing technology paradigm shifts.

The periods of reorientation are essentially unpredictable. However, one may develop some sensitivity for them by focusing in the planning of the project on the expected bottlenecks in the development of the new technology. This is somewhat similar to Goldratt's Theory of Constraints (TOC) for the scheduling of the manufacturing operations of a plant: the output of the factory can be maximized if one first plans for maximum utilization of the bottleneck capacity groups and subsequently derives the schedules of the other capacity groups from the schedule(s) of the bottleneck group(s) [Goldratt & Cox 1986].

A similar approach for managing product pre-development has been developed by Boersma [Boersma 1994]. Along these lines, typically in technology development focus is applied on the better known issues to create some knowledge base with respect to the new technology from which then to tackle the more difficult issues. However, Boersma gives a number of reasons for first tackling the bottleneck issues and he developed an approach for doing so. Making an inventory of the major bottlenecks in development and focusing planning on these bottlenecks can create sensitivity for possible needs for reorientation. An awareness of possible needs for reorientation, together with this sensitivity of where and when they may occur may support developing a timely and effective approach to reorientation.

Secondly, the punctuated equilibrium model suggests that, once the development process stalls, one should act differently from mainstream or evolutionary technology development, commonly performed while following the existing technology paradigm. Management tends to put in this phase just more effort in the project; pressuring researchers, promising bonuses, adding capacity and seeking help from the outside in

Chapter 8: Towards Managing CFR

capacity or knowledge. This management practice is justified as the problem solving is executed within a known framework and the management counts heavily on the assumption that it is only a question when the evolving technology is available and that the question if the new technology becomes available is irrelevant. This itself already shows the magnitude of the shockwave that propagates through the organization when the if-question becomes relevant just because the paradigm ends and an evolving technology is meaningless to the organization.

Focusing has become meaningless, just because it is not clear on what to focus. Routines become useless as they constitute the focus on matters that have been meaningful in the past. For an organization this is a confusing phase, where the existing management practice has become ineffective. In radical technology development it should be realized that periods of reorientation are 'normal' events, during which most effort should be put in finding a new direction, rather than in solving the next technical problem. The duration of this reorientation process cannot be planned; in radical technology development it is more or less a given that it is unknown when the reorientation constitutes in a new technology paradigm that can be followed. This is an important difference for management; it has to shift from a situation where only the "when" has to be managed and not the "if". Thirdly, one may use a (possibly adapted) stage gate system [Cooper 1990, 2006] to manage radical technology development. The choice of gates may use the analysis of the possible bottlenecks mentioned above. The major implication of the findings of this research is, however, that once it proves to be too difficult to pass a certain gate, one should not just do more of the same (e.g. , increasing pressure, adding capacity, etc), but also look into the issue of whether a reorientation is needed. So one should not stay immersed in the solving of the next technical problem, but also look at the project at a more fundamental level.

In the fourth place, monitoring the fluctuations in CFRs, both at the level of researchers and at the level of management, is important. One can monitor these CFRs by asking around or by putting it on the agenda of a department meeting; one can also measure these CFRs from time to time, as has been done in the case described in Chapter 6. Diagnosing a need for reorientation can be supported by these measurements: if progress has become sluggish, but the CFRs remain robust, one may decide to stay the course. If, however, progress has become difficult and the CFRs have deteriorated, one may need a reorientation. Management needs anyway to know of a possible deterioration of CFRs. If it seems to be warranted, one has to reassess the potential of the new technology in order to possibly start a reorientation process. But if it seems to be unwarranted, one also has to reassess this potential to rebuild confidence otherwise the deterioration of the CFRs will become a self fulfilling prophecy.

In the fifth place, once one does need a reorientation, much effort should be put into finding a new direction and building new or adapted CFRs, both at management and at researcher level. To do this one needs much interaction between the various parties in development, for instance by organizing a number of workshops. Finally, also during

equilibrium periods one should keep the present CFRs mature by challenging them from time to time, e.g., by scans of the technical and commercial environment and by allowing 'advocates of the devil' to state their case.

8.5.1 Influencing the CFR

The paradox of the CFR is that it apparently has a large influence on the organization in relation to the punctuated equilibrium character of paradigm shifts, but it cannot be controlled in a very direct way. On the one hand this is a management issue, but on the other side it offers surprising results that can promote radical innovation in an organization.

The CFR can be partly made explicit, but is mostly implicit, especially if a diversion of the existing paradigm takes place. The reason is actually quite obvious; individuals are starting to think and act in a way that is different from the prescribed and explicit part of the existing CFR, which is embedded in the routines, goals and strategies. This non-conforming behaviour starts off implicitly and plays initially only in the mind of an individual. This implies that the non-conforming behaviour can only be conditioned, and not so much controlled, as controlling would imply that pre-information is available and that non-conforming behaviour is explicitly imposed. If this is possible at all, it can be argued that imposed non-conforming behaviour is actually conforming behaviour and therefore it can be concluded that non-conforming behaviour by definition cannot be controlled or can be created by intervention. By creating an environment that tolerates non-conforming behaviour of individual members, a mechanism can be brought into place that offers the option to question the current CFR, to allow it to deteriorate and to eventually adopt a new CFR and follow a new paradigm.

Non-conforming behaviour can easily be seen as contra-productive, disturbing, jeopardizing, undermining etc. With a generally accepted organizational structure where management constitutes from leadership and where there is an expectation that directions need to be followed in order to obtain the goals that the organization has set, it is most likely an unpopular idea to stimulate individuals to ignore the given direction and basically allow them to go in a different direction and therewith allow them to not longer contribute to common goals.

A model where an organization is absolutely intolerant to non-conforming behaviour implies that change can only come from the absolute leadership. This model can work if the leaders have an absolute knowledge and the organization can follow any change in the leadership's (non-collective) frame of reference. For a practical implementation of this model, the (classical) army organization comes to mind; troops follow orders to the letter and any deviation of these orders is seen as defecting and will be punished accordingly. It is fair to say that a management implementation of this model may work in some situations but with the migration to multi-disciplinary, more complex organizations with higher skilled and specialized individuals, management of the

organization is forced to migrate from a position of absolute leadership to a position of facilitating leadership.

In the situation where leadership does not have the absolute knowledge to manage all the activities in an organization, it not only has to rely on critical information from several individuals within the organization but also has to merge many opinions and ideas into a meaningful direction for the organization. This is one of the important reasons that the Collective Frame or Reference is very relevant for organizations that rely on the facilitating leadership model. The creation of a mature CFR within an organization provides leaders with a mandate to steer the organization in a direction that aligns with the CFR and maintain this direction while the CFR lasts. It also implies that the leadership has to bear non-conforming behaviour that can lead to a chain reaction, breaking down the CFR that provided management a mandate to give direction along that CFR. Still, this does not imply that an organization is fully submitted to non-conforming individuals resulting into full scale anarchy. As discussed in Chapter 5, an organization contains several CFRs that are in different states of development, some are mature and persistent, others are just developed; CFRs change over departmental boundaries, some CFRs are more dynamic than others. This creates a situation where leadership can allow changing within an organization as long as it still contributes to the overall mission of the organization. Figure 8.5, shows the management process of an organization described by Weggeman [Weggeman1995]

This model shows that management obtains information from the environment, it measures the organization processes and it controls the processes based on an analysis of the measurements and the information obtained.

Figure 8.6 shows the management process including the 'CFR-dimension'. The notion here is that with the CFR dimension the management model has been changed from an absolute leadership model to a facilitating leadership model. The CFR model converts information from the environment to perceived information; it is colored by the

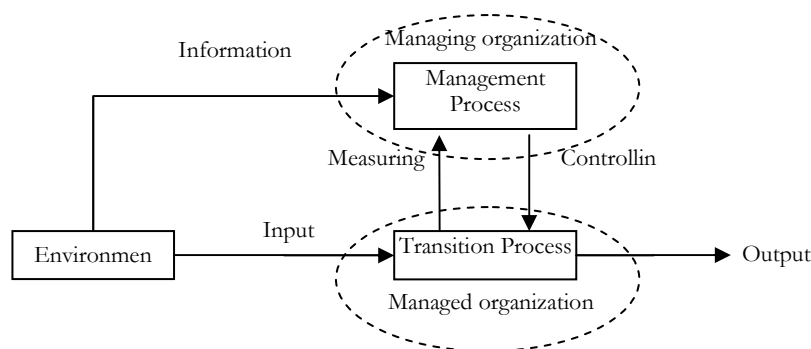


Figure 8.5: The management process which is top-down oriented; management interprets information gathered from the environment which is applied to the management process

receivers and it contributes to a perceived image of the environment rather than an absolute image of the environment. Also, it allows bottom up input from the organizational processes. This input represents perceived information on the best route, given the constraints from within the organizational processes. Although this is not always relevant with respect to many organizational processes; it is argued that this is very important for technology development processes. Technology development requires highly skilled professionals that are able to follow technology trends beyond the boundaries of the organization and these professionals are able to provide unique solutions within the context of the organization. This context is not only given by the management of the organization, but also by the professionals who are embedded in various networks ranging from user network to scientific networks. The value of this bottom-up input is too precious to be overlooked and recognition by management that this factor is present provides additional input to strategy development.

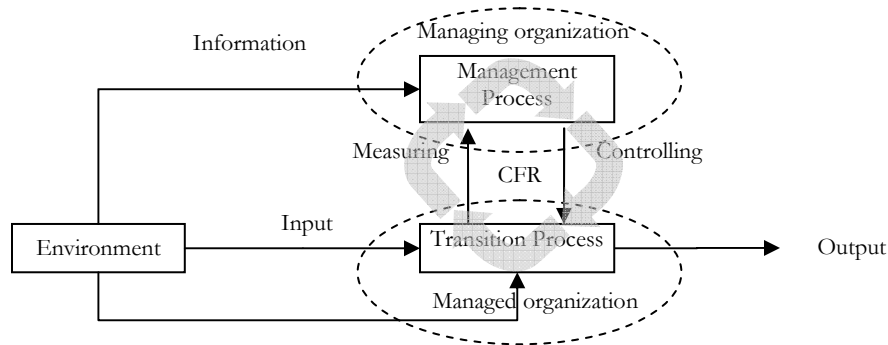


Figure 8.6: The management process which is CFR oriented; both the managing and managed organization interprets information gathered from the environment which exchanged by the CFR.

It is important to realize that technology development in itself is a change process that needs to be managed and controlled. Interestingly enough the classical view of a management that imposes change on the organization and deals with the resistance can be fully reversed as well; bottom up initiated technological change can meet resistance at the management level which leads to failure to accommodate the change [e.g., Symon 2005].

8.6 Guidelines to manage the paradigm shift

The timing for changing paradigms is difficult to determine, especially as the sequential steps upon a successful product introduction are uncertain and can easily delay the process and change the timing. Changing the timing may affect the window of opportunity to bring a new technology successfully to the market. This works both ways; bringing a technology to the market too early is inefficient and allows

competitors to make up the difference in advancement relatively easy. The organization needs to spend a lot of effort to create a demand and educate the market about the technological advantages, before it can generate sales.

Bringing a new technology to the market too late results in a reduction of the value of the technology and the likelihood of competing technologies emerging is larger. This is inefficient as the organization has to deal with lower Returns On Investments affecting the financial position of the organization.

Criteria for what is too late or too early are hard to give as a number of factors that play a role are numerous. However it can be assumed that there are two important parameters that are relevant for the progress and timing of the technology paradigm shift; risk and effort. Based on these two parameters, seven identified aspects determine the outcome of the paradigm shifts in terms of timing and effect. Aside from a description of the phenomena, in Appendix A some management methods are discussed to manage the particular aspect.

1. The level of definition and broadness of recognition of technological needs of the market

The needs of the markets are not always well defined, especially with respect to a new technology. Before a paradigm shift, the market is used to a product that consists of a composition of certain technologies. The market has a good understanding of the functions of the technologies and its merits. Also the market is used to the evolutionary developments and the relative impact of those developments on the performance of the product.

Introducing new technologies to this market in such a form that is observably different from the previous generations will change the performance of the products. In an ideal case the market has a clear demand for the new technology as it provides anticipated advantages with respect to product performance. Unfortunately, this is often not the case; the demand and the technology are not necessarily coupled. Especially in the case that an unknown technology is introduced that is fundamentally different from the previous one, the market needs to obtain an understanding of what the anticipated benefits are of the new technology.

Once this understanding is developed, a 'real' demand for the technology is created and the market needs become well defined. The broadness of this demand is also an important factor; ideally the technology should provide benefits to every user in the addressed market. However users in the market are all slightly different and the impact of the new technology is not necessarily the same for every user in the market.

2. The level of maturity of the technology

Before a technology is ready to be implemented into a product, it passes multiple stages of development. An organization shifting to a new technological paradigm adopts a new technology that is in a certain stage of development or has a certain maturity. A technology in its early stages requires not only effort to bring it to a level where it can be implemented into a product, there is also a higher risk associated to it. The risk that a new technology in its early stage is not suitable to be implemented into product for the intended market is higher than when a more mature technology is adopted.

3. The determination of long term trends and the impact for/from the new technology

In the orientation phase of the organization, the organization will explore both the long term technological and market trends. It is difficult to predict characteristics of current markets over a time span of five years or longer and even more difficult to determine the characteristics of the new markets. A more widely oriented trend analysis can be used to determine longer term trends. This analysis is not necessarily market specific, but it is relevant to do this analysis for high level markets which the organization is addressing or considers addressing. Examples of these high level markets are: Medical market, Homeland Security market, Digital Still Camera market etc. It potentially shows future developments that can affect the market positively or negatively. Performing the analysis in a broader sense shows potentially the future developments in society, which may reveal potential new markets

4. The magnitude of the gap between the current and required technological and organizational capabilities

The gap between the current state of the organization in terms of capabilities, practices and knowledge and the requirements that the new technology imposes on the organization determines the success. When the implications for the organization are significant in terms of the available knowledge and capability, the organizational change that is required adds additional risk to the organization.

The case presented previously where an organization is considering a new imaging technology, the gap between the current state and required state is relatively small; the material system is the same although the development and manufacturing process is different. The organization has to generate new knowledge, but the old knowledge is not fully obsolete. Also, the current organizational processes and procedures show enough similarity to benefit from 'reuse'.

If the technology is more radically different, the reuse is limited and it means that the organization needs to develop itself into something quite different from what it was before. This requires a more radical process, which is more painstaking and risky. In some cases the gaps cannot be defined as a particular technology, or are related to a particular implementation of a known technology. In these cases the technology gap is described as a functional requirement, to which one or more technologies may fit. The same is actually valid for other organizational capabilities; the new paradigm not necessarily points at a well described capability, but specific requirements can be deducted from the paradigm shift.

5. The financial bandwidth for the development of the new technology

Technology development requires sufficient resources over a time span of many years. The organization has to feed this process by resources. These resources, whether they are direct, e.g., investments, or indirect, e.g., labour, are sourced out of the finances of the organization. In order to justify the allocation of financial means, the organization

Dialogue box 8.2: 911 and the imaging markets

The terrorist attack on the world trade center has had a huge impact on the imaging markets. A few hours after the attacks the USA declared the war-on-terror and announced far-reaching security measures. The statement of President Bush “you’re either with us or against us”, left not much choice for other western countries than to follow these developments. Several ‘war-on-terror’ programs have boosted imaging technologies in many areas. Aside from the imaging needs for the deployed troops in Iraq and Afghanistan, where soldiers are fighting opponents that are hard to identify as they are embedded in the population, the protection of the borders and security of air traffic has grown tremendously. The luggage security checks have been increased and are still increasing. The developments in new explosives are driving new imaging technologies like Terahertz, that (potentially) are able to combine spectroscopic functionality (what is it?) with imaging functionality (where is it?). Day and Night cameras, that can trace suspicious movements on airports, harbors and at the borders, are deployed by the millions. Satellite deployed imaging systems are deployed to monitor threats on a more global scale. Aside from the hardware, ‘intelligent’ software is developed that can trace movements, or notice changes in configurations in order to help apply focus in the massive data streams that are produced. It is expected that these development do not stop for the coming years; the war-on-terror will last for many decades if it will end at all. Back then in 2001, a clear trend for imaging markets became apparent; a strong demand for imaging based defense and security systems was imminent.

will have to make a trade off between the total required investments and the expected future benefits. This is not an easy task as the benefits of the development may be enjoyed years after the first investments need to be done. However, creating a

technology business case is a useful tool to monitor the progress and update the market expectations along the technology development process.

6. The availability of technology partners

Technology partners can help to de-risk the technology development and/or increase the technology readiness level. Technology partnerships allow the organization to source critical technology from partner organizations that are specialized in this technology component and reduce the risk of a development from scratch. Unfortunately, the most suitable technology partner is not necessarily interested in providing the technology, especially if there is a significant overlap in the commercial activities of the organizations. It is logical that there should be an obvious win-win situation to promote the technology partnership in both organizations. Aside from the first order attractiveness of partners, the collaboration of organizations is not obvious. For example Larsson et al. states that good partners need to develop 'collective learning capabilities' in order to obtain a fruitful cooperation [Larsson 1998]. Moreover Nooteboom et al. relate the cognitive distance of partners as a measure of successful corporation [Nooteboom 2007]

Still, it is not excluded that two commercial competing organizations will still gain mutual benefit from a technology partnership [e.g. Burgelman 2001, p.650, Spencer 2003].

7. Managing the Collective Frame of Reference

Adopting the notion that the CFR drives paradigm shifts implies that the paradigm shift can be influenced by managing the CFR. As said in the previous section, it is hard to manage the CFR directly, but monitoring the CFR can help to understand what the state of the organization is with respect to a certain direction. Even when the build-up

Dialogue box 8.3: Two competitors join technology development forces

Philips Electronics and Sony decided in the '90s to cooperate on DVD technology. Evidently both organizations saw a mutual benefit in sharing technology components and promote a certain standard. Cooperating on this standard by adding mutual technology components together, provided a stronger position compared to other proposed standards. Both organizations did benefit from owning the Intellectual Property that formed the foundation of the standard. Still, Philips and Sony were direct competitors in the marketplace for DVD players and recorders.

or the breakdown of the CFR can only be conditioned, it is still useful to use this

somewhat limiting handle to maneuver the organization towards a new paradigm. The management of the CFR is particularly discussed in the next section.

8.7 CFR Monitoring and Conditioning

For the method to manage the CFR a distinction is made between the monitoring of the CFR and conditioning the CFR. For the monitoring, some tested and untested methods are discussed, while for the conditioning, factors are identified that can provide conditions for the development of the CFR. This can either be conditions to breakdown an existing CFR or condition to create a new CFR supporting a new paradigm.

The CFR can be monitored by several techniques, among interviews, questionnaires, presenting propositions in group meetings, one-on-one meetings. The idea behind each of these techniques is that individual members of the organization provide their vision on the technology potential of the organization or that of the main competitors. This vision is thought to provide important information about the frame of reference of the individual. By comparing the vision of one individual with other individuals collective factors emerge, contributing to a Collective Frame of Reference. This process can also be conducted in group sessions, where the CFR can be measured against the unanimity of the reactions on propositions related to technology potential. This monitoring can be done within sub-divisions of the organizations and for different technology aspects. The maturity of the CFR can be evaluated by monitoring changes in the vision on technology potential over time. A consistent vision indicates a persistent CFR relating to the subject.

Also important is to map how individuals are connected to external networks that provide an influx of technology information to the organization. The vision on the technology potential of an individual that is well connected to external networks carries an external component, which should be weighted differently (see dialogue box 8.4).

Some of the internal factors stated in Chapter 5 that constitute to the CFRs are potentially parameters that can be influenced, and therewith provide handles for management to influence the CFR in the organization. These parameters organized in activities that management can consider to influence the CFR; gathering and providing information, connecting to particular external networks, managing confidence, plan for success, managing risk perceptions, allowing non-conformist behaviour, manage CFR propagation.

A: Gathering and Providing Objective Information

Managing the flow of information is considered a very important factor to influence the CFR. The reason is actually quite simple; anticipating that any piece of information that is processed by individuals, contributes to the belief of that individual. The interpretation of information can either reinforce or weaken the personal belief of individuals. Allen studied the influence of information on the success of technology developers, and showed that effective information transfer correlates with higher success rates of technology development [Allen 1977]. A wider body of literature on the information processing theory and more specific communication in R&D point at the importance of information processing in R&D programs [Galbraith 1973, Tushman & Nadler 1978, Tushman 1978, Berends 2003].

The Information Processing Model basically assumes that information reduces the uncertainty and ambiguity of complex tasks. However Berends found that this is not always the case; in some cases new information increases the uncertainty and the ambiguity in an organization. The cases study, showed many of these events as an exponent of the creation and destruction of the CFR in the decision process associated with technology development. An individual can find reassurance of the personal belief if the interpretation of the information aligns with the belief.

It should be noted that this is a subjective process; individuals are subject to self-reference so it cannot be excluded that a certain belief will color the interpretation of the information. This is in line with the notions given by Kuhn, related to scientific paradigms; conflicting information or anomalies do not directly result in a paradigm shift. This seem to be related to a blind spot of individuals and organization as described by Vos' thesis on self-referential systems [Vos 2002, p29-31]. Whether this self-reference dilemma is hampering the 'good' conduct of decision processes or not; it seem to be a factor that may keep an individual 'on track' without reconsidering its belief, even when conflicting information is provided.

The weakening of an individual beliefs results in an openness of the individual to consider alternative beliefs. This is not a straightforward process. Early work of Polanyi deals with the stability of (scientific) beliefs which seem to be very applicable as well [Polanyi 1952]. According to Polanyi individual beliefs can be embedded in 'tradition' that is part of a 'conceptual framework' and that contradictory information has to overcome the conceptual framework in order to alter the individual belief. So in general it will take effort to reconsider ones beliefs; an individual has to overcome an 'internal resistance' to let loose the beliefs that are in conjunction with ones conceptual framework. Providing a flow of objective information and providing the means to process this data in an efficient fashion will help for the 'good' and for the 'bad'. On the one hand, if the objective information is interpreted by the individuals in such a way that the CFR is reinforced this can be considered as good; the organization is doing well, while following the existing paradigm and the members of the organization

have the impression that this is sustainable. On the other hand if the objective information creates a weakening of the CFR, it can be expected that this is for good reasons; the members of the organization have the impression that following the existing paradigm is not sustainable and that change is required.

B: Connecting to the External Networks

Another factor influencing the CFR is establishing connection to external networks that can provide useful information about the state of the technology of the organization. Monitoring trends in technology allows the organization to anticipate better on 'sudden' external changes. These networks comprise scientific networks (see dialogue box 8.4), supplier networks, user networks and other networks like for example economical think-tanks that can provide information about trends in future needs. Management of an organization can influence the CFR by assuring that professionals in the organization are connected to the relevant networks.

Equally important is that the professionals connected to these networks are provided with means to communicate these trends within the organization. Aken & Weggeman reported on external networks and the importance of these networks especially in the Fuzzy Front End of the innovation process [Aken & Weggeman 2000]. As discussed in Chapter 1, it is argued that the fuzzy front-end comprises the technology development process and therefore these findings seem to be very relevant for the conditioning of the CFR by realizing relevant connections to external networks.

Recent developments in network theory and more specific alliances, focuses on the role of social networks on the creation of alliances [Gulati 1998]. Gulati found that the degree of entrenchment of an organization in a network determines the information streams towards the organization. Lemmens studied specifically the effects of evolutionary and disruptive technological changes on organizations that are part of an alliance compared to organizations that are operating outside an alliance [Lemmens 2003]. Lemmens concludes that organizations embedded in an alliance are coping better with technological change than organizations operating outside an alliance [Lemmens 2003, p.120]. This could imply that when indeed the CFR present in an organization is exposed to influences of an external network, it allows for a better anticipation on external changes that influence the performance of the organization. Aken and Weggeman make a distinction between formal and informal innovation networks. Informal innovation networks between organizations comprise (social) relationships that are not (fully) formalized in the form of agreements on defined exchange of information. These informal networks provide benefits to the organization as it links knowledge fields together that are not available within one organization. The end result is a reduction in the risk and effort and, perhaps most importantly, it provides insight in the potential of new paradigms [Aken & Weggeman 200, p.143].

Again it can be argued that these informal networks influence the CFR positively in terms of risk perception, feasibility and additional insights in potential. Aken & Weggeman propose the following prepositions for selecting partners for a successful informal network: There should be a balanced mutual interest between the partners, and this mutual interest can be satisfied for both parties at similar time scales, and the basic knowledge level should be equal.

The latter is studied in more detail by Nooteboom et al., in an attempt to measure the cognitive distance between network partners, and argues that there is an optimum cognitive distance for a successful partnership [Nooteboom 2007]. Managing the informal innovation network is difficult as it requires balancing between insufficient management attention and too much management attention; Aken & Weggeman call this the Daphne dilemma related to the mythical interaction between the morning dew (Daphne) and the sun (Apollo) and the notion that if Apollo encloses on Daphne, Daphne vanishes.

Similarly, Aken and Weggeman propose to utilize a so-called type 2 management system, tight enough to allocate resources for informal innovation networks (unlike the type 3 management system), loose enough to keep it outside the formal, mainstream project management structures (unlike the type 1 management system). On a more general note, Aken & Weggeman state that a type 2 management system is suitable to guide the decision processes that are related to the STO and ITO stages as discussed in Chapter 3.

C: Stimulate Confidence

Many organizations are aware that celebrating success is important to stimulate the confidence level in the organization. Showing the success stories internally is important, but for the CFR it is also important that previous failures are well understood. An organization tends to generalize failures in a sense that everything that is outside the comfort zone of the organization is doomed. In case of radical technology development this can be indeed one or two successes out of ten attempts and an organization has to manage these failures in such away that new opportunities are still considered even if it went wrong the last time. Learning from failures is important and should be based on a thorough analysis of the failures, which generates knowledge rather than defining 'no go' areas. Another maybe more straightforward factor to influence the confidence level in the organization is to develop plans for success. Especially an organization in crisis tends to set goals very tight, because time is of the essence. This is very understandable, but if the plan is perceived by individuals as unrealistic, it hampers the confidence level in the organization. Another important factor is the risk perception that is present in the organization. It is, however, assumed that this risk perception is directly linked to the confidence level in the organization, how past failures are perceived and how realistic the development plans are [see e.g. Sitkin & Pablo 1992].

D: Allowing Non-Conformist Behavior

This may be the most difficult factor to manage, as the traditional management techniques assume that all members of the organization follow the strategy and contribute to the goals that are set by the management. Any behavior that is not contributing and sometimes contradictory to the strategy can be seen easily as unwanted behavior. However as this non-conformist behavior is a source of organizational change, it should be tolerated by the organization. This does not mean however that the organization should fall into an anarchy that jeopardizes the short term continuity of the organization. Consequently, management has to channel the non-conformist behavior by facilitating this behavior, without affecting current operations too much. In summary this means that a part of the organization or some individuals are allowed to conduct a reorientation on alternative paradigms and therewith are not contributing to the current goals of the organization.

Once this reorientation process is leading to a new prevailed direction, i.e., a new CFR is created within this subset of the organization, this new CFR is propagating to other parts of the organization that are impacted by the new paradigm. One possible organizational implementation is to define a multidisciplinary sub-organization or teams that have a 'pathfinder' mandate; find new technological paradigms that provide sustainable growth in the foreseeable future. [e.g., Christensen 2000, p.73, Wheelwright & Clark, p.194, 200].

8.8 Timing of the paradigm shift

The seven factors described in the previous section all influence the timing and duration of the technological paradigm shift; finding a good partner organization, or having excellent funding can help to manage the window of opportunity. Still an organization can mismanage the timing and duration and can spend too much effort and shifts too early, or does not spend enough effort and shifts too late. Maybe the right timing is best illustrated by the consequences of two extremes of the spectrum; shifting too early or shifting too late.

Shifting too early: The burden of Technology push

A shift that is too early results in major investments in new technologies, while the market is not ready to adopt the new technology. In this scenario the organization pushes the technology in order to convince the market. This requires a large effort as the organization attempts to enforce a certain need onto the market. The organization is required to spend large amounts of resources while the first revenues are pushed out. Being first to the market offers a limited advantage; the risk is that the market is addressed with a technology centered focus, while less attention is paid to actual market

demands. This is logical as the market did not have a particular defined need in the first place. This means that the organization has to make a shift from the technology push phase to a market pull phase in order to maintain market leadership. Missing this shift results in temporary leadership of the pioneering organization, which is taken over by competitors that focus more on market demands and which are better capable of offering products that comply with the newly created market needs.

Shifting too late: The burden of non-sustainability

An organization that shifts too late finds itself in an acute situation where the products are not capable of satisfying the needs in the market place and the organization has to shift rapidly to a new technology to catch up with the market needs and most likely with competitors that anticipated better on the market changes and made a paradigm shift earlier. A shift too late affects the market position and the organization will lose market share. Unless the organization can regain this market share on the short term, the sustainability in this particular market is at risk.

Shifting on time: Sustainability and growth

A timely shift allows the organization to grow and secures the sustainability of the organization. The basic rule is here that the organization should never experience a downturn in their revenue due to incompatible technology. Although the rule is simple, foreseeing this downturn and avoiding it is difficult and hard to manage. Still some guidelines here are:

- Creating a pool of technological options, trading off the required investments to maintain the pool and the benefit of having options available that reduce the risk. Especially larger companies can take advantage of this approach; for example organizations that can permit themselves to maintain an industrial research lab that generates technological options by the number, maintain a large technology pool. There is an interest for these larger organizations to provide unused technological options to other parties and trade them for technology options that are more appropriate. Recent developments known as “open innovation” relies partly on this principle; innovation spill-overs are brought outside the boundaries of the organization. Smaller organizations have to rely on a less extensive technology portfolios and as the business activities are confined to niche applications that in general are more sustainable and less susceptible to abrupt technology changes, small organizations can cope relatively well with this uncertainty.
- Technology Life Cycle management provides the organization more visibility on the status of the current technology concerning its potential to provide a certain performance. Foster argues that an older technology forms not so much a hard limitation on the performance of the product, but that the effort that is required to improve the performance increases significantly after time and that the price-performance drives the organization to a new

technology[Shanklin & Ryans 1987, p.107]. This suggests that the organization can monitor the increasing product development cost necessary to obtain a certain product performance as a measure to see when a new technology is required. This provides a more forward looking capability provided that no disruptive substitute technologies are introduced.

- Observing trends in applied science can provide a forward looking capability. Applied science can be seen as the front end of technological developments. In general, scientific conferences are organized around a particular technological application area. By observing trends in these conferences, an expectation can be formed about what the technological needs are in the near future. For example for medical imaging applications, every year a conference on medical imaging is organized where universities and research institutes present the results of new medical modalities. A selection of these modalities ends up on the medical markets after three to five years. These conferences give a good impression which technologies need to be commercialized in order to support the new medical modalities. It not only points the experimental setting towards certain technology blocks that are required, also a specific critical performance is given that is require to make the modality meaningful.

8.9 Organizational factors of the paradigm shift

What is a proper composition of organization members in different phases of the paradigm shift?

Based on the phases of the paradigm shift shown in Figure 7.4 a description can be given of the type and character of the organization members that seem the most appropriate during that particular stage of the paradigm shift.

The organization in equilibrium; the recurring phase of the paradigm shift

The CFR of the organization is uniform enough in order to obtain the required goals and fulfill the organizational mission. Moreover, the CFR and the proposed strategy are fully in line; all the critical elements in the organization subscribe the strategy and recognize that the strategy represents the proper sequences of actions in order to realize the organizational goals. This mode of operation requires no particular skills or qualities other than that which are required to execute process tasks and routines that will have known results and progress [e.g. Feldman & Pentland 2003]. The organization in this phase will benefit from so-called ‘routiniers’²¹, which are able to execute tasks that are predictable and recurring. The routiniers convert their experience which they gathered over time into efficient processes that minimize the effort and increase the

²¹ Routinier (French origin) is defined here as a person who has a large experience and can use this experience to execute recurring tasks in an efficient way.

productivity. An organization that has the opportunity to operate its processes for a longer period without interruptions benefits by having these routines in place as it will increase the productivity, competitive power and profits. In a way the routines are similar to the so-called 'adaptors' in an organization [Kirton 1976]

Questioning the current CFR: Planting the seed of doubt

Before an organization enters a reorientation phase, a seed of doubt is placed by an individual member in the organization, questioning the existing CFR. This is not a unique moment; it is something that most likely happens on a daily basis and throughout the organization. The difference between a sustaining CFR and the breakdown of the CFR is how the seed of doubt is propagating through the organization. In some cases the breakdown of the CFR is limited to the individual who placed the seed or a small group of allies, but apparently the propagation comes to a stop and the CFR remains intact. In other cases the breakdown propagates further and requires management intervention.

The opposing frame of reference are seeded by an individual with a low threshold for accepting change and who has sufficient self-esteem to oppose the ruling CFR. These individuals are not necessarily Change Agents as they are not necessarily interested or skilled in implementing change in an organization. Also the motivation to induce change is not necessarily inclined by moving the organization closer to its goals or fully in line with the mission of the organization. Motivation can be very personal, like boredom, due to recurring activities, anticipated personal gains like obtaining prestige and importance in the organization. Whatever the origin of the motivation of this individual, it creates a disturbance of the equilibrium that is exploited and maintained by the routines.

The organization is subject to this disturbance and members may reconsider the existing CFR and either support or reject the CFR. The intriguing part of this process is that the opposed frame of reference is judged on its merits by organizational members that are not necessarily aware of the motivation of the individual placing the seed of doubt. Paradoxically, it seems irrelevant what the initial motivation was of the individual seeding the opposed frame of reference, as it gets filtered out by other individuals in the organization and therefore a good change can come from the wrong, individually motivated reasons.

Consequently, individuals that are driven by personal motives still have value within the organization as seedlings of opposing frame of references. The main characteristic is that the individuals have enough self esteem to oppose the existing frame of reference.

Reconsidering the organization; the reorientation phase of the paradigm shift

Important for the reorientation phase is that individuals take ownership of the opposing CFR and build a case to convince the organization that the existing CFR can or should not be maintained. This requires thorough preparation and time to bring all the options at the table so that a balanced deliberation can be made, resulting in a decision to change the paradigm. This preparation is basically gaining knowledge of alternative technologies and/or principles that can be used. In some cases the technology is applied in other areas or even used by competitors; in other cases the technology is not present but the scientific principle that can result into a new technology is present and identified.

Whatever the status of the technology, the organization needs to learn about it and gather knowledge not only about the principles of the technology, but also about the principles that are required to apply the technology successfully into a product. A Change Agent needs to coordinate this knowledge gathering and preferable has enough technical insight to separate the main bottle necks from the lesser issues. This also requires a thorough insight of the current capabilities within the organization in order to define an accurate gap analysis that can guide the organization to addressing those gaps.

The required skills for this process comprise not only large persuasion power, but also the ability to understand change processes and how to conduct those from within the organization. It is often not as simple as just convincing the management of the organization to adopt a new CFR; as the organization running on routines that contribute to the operations of the organization. Routiniers will protect these routines and often for very good reasons; the routines allow an efficient operation and continuity of the revenue streams generated with the existing paradigm. A Change Agent should have an eye for the importance of the existing processes as well and maneuver through these existing structures, rather than taking them down. Therefore a Change Agent requires a broad set of skills, ranging from convincing management to decide on a new paradigm and implement this change into the organization. Although parts of the organization have to be changed and/or removed, it requires diplomacy to do this in a way that the relevant structures of the organization remains in tact.

This is in line with the notion that there will be a relevant structure left after the decision to change the paradigm, as it is unlikely that the organization decides to become irrelevant.

On the new path; the implementation phase of the paradigm shift

Once the Change Agents have paved the road to a new paradigm shift, the actual implementation requires various skills that can be categorized in technology development program managers and product development programs. Depending on the status of the technology, the organization may have to develop the technology

further before it can be implemented into a product. The earlier presented technology readiness level is determining whether the technology can be pushed to a higher readiness level within the setting of a product development program or may require a more dedicated technology development program.

The former case can be identified as a product development program with a higher than normal risk, but can be managed with the available program management techniques that are not different from regular program management techniques. In the latter case it requires a program manager who has sufficient understanding of the technology to push the fundamental specifications to a level that makes it suitable to implement into a product. This activity will initially be very broad; many parameters need to be evaluated initially, while later the focus will be on more specific parameters that need to be improved.

Making progress is difficult and unpredictable, but it still requires a structural approach in order to plan resources and activities properly. The program manager of a technology development program needs to have enough endurance to proceed on a path without the knowledge that a solution can be found, while on the other hand should be strong enough to propose a new path and leave unfinished business behind. This program manager position can come with a lot of stress, as an organization likes to set clear targets and preferably an end date of the activities on the one hand, while the character of the work does not offer any certainty that success is emerging or imminent.

The resources are often limited, which limits the number of parallel paths that can be followed, if that is possible at all. The technology development program manager needs the skills set that are equal to that of a scientist, although the motivation for the activities is fundamentally different. The technology developer needs to deliver results that can be applied in a product, while a scientist needs to produce results that are publishable.

Back to ‘normal’; the recurring phase of the paradigm shift

Once new products are developed based on the new technology and these products are manufactured, the organization enters an efficiency improvement phase where routines are created to improve the processes ranging from product development, to manufacturing, to managing the supplier network. In this recurring phase the technology is still developed but it is an evolving development that can be managed in a very similar fashion to product development, and often the evolutionary technology development is incorporated into the product (pre)development programs. This kind of technology development may not be fully executed in routine but as the outcomes are more predictable, allowing for better planning and scoping. In this post paradigm-shift phase the organization benefits from routiniers who are able to obtain efficiencies that are required to improve the competitive position of the organization.

Making up the balance: Routiniers, Change Agents and self-confident individuals

The characteristics for a routinier and a change agent are very similar to the distinction that is made in the evolutionary economics between the work of Schumpeter and that of Nelson and Winter. While Schumpeter pointed out the characteristics of entrepreneurs that bring actual change to the economic system, Nelson and Winter point out the importance of routines in an organization that progress by variation and selection. This applies very well to a perspective of technology development along a technological paradigm, where a routinier is a skilled individual who applies routines to realize incremental technological change within the organization. Schumpeter however considered the role of an entrepreneur as an individual who takes up larger organizations that seem to be unable to realize enough dynamic momentum to realize radical change. This suggests that radical change within the organization needs Schumpeterian entrepreneurship within the organization. With the perspective of changing the technology paradigm, and start technology development along that new technology paradigm requires a change agent that has not only skills that are similar to Schumpeter's entrepreneur, but also skills to implement change in an organization that relies on routines.

	Change Agent	Routinier
Technology Development	<ul style="list-style-type: none"> - Radical - Routine changing 	<ul style="list-style-type: none"> - Incremental - Routine enhancing
Change	<ul style="list-style-type: none"> - Punctuated - Out of equilibrium 	<ul style="list-style-type: none"> - Continuous - Towards equilibrium
Entrepreneurship	<ul style="list-style-type: none"> - S-type - Expansion of choice - Creation of potential 	<ul style="list-style-type: none"> - A-type - Suppression of choice - Realization of potential
Organizational Behavior	<ul style="list-style-type: none"> - Change driven - Heedful non-conformist behavior - Drives breakdown of existing CFR - Drives Reorientation - Creates new CFR - Stimulates propagation of CFR 	<ul style="list-style-type: none"> - Efficiency driven - Conformist behavior - Reinforces current CFR - Focus on current paradigm - Limits disturbances

Table 8.5: The distinctions between routiniers and change agents in a technology developing organization similar to the distinctions made between S-type and A-type entrepreneurs [Cheah 1990, Nooteboom 1993] and between Schumpeter and Nelson and Winter [Boer 2000].

Being an entrepreneur or change agent within an existing organization is, in many aspects, more difficult. A change agent needs to drive novel ideas on the one hand but also needs to maneuver through existing structures within the organization. This requires maneuverability and creativity, even if the management of the organization has defined a clear mandate. For management it is also a balancing act; on the one hand the organization should realize its short term goals, while on the other hand also support change processes that can bring long term growth and sustainability. Unfortunately, it is not that simple to provide a change agent with an unconditional mandate to implement the change, and it requires heedful actions to implement the change processes. This heedful acting is a quality that is required from a change agent.

Along the distinctions made by Cheah [Cheah 1990] and Nooteboom [Nooteboom 1993] between so-called Schumpeterian type (S-type) entrepreneurship and Austrian type (A-type) of entrepreneurship, which is a type of entrepreneurship that resembles evolutionary economical developments very similar to Nelson and Winter's evolutionary economics, Boer [Boer 2000] made a distinction between the regimes of Schumpeter and Nelson and Winter. Projecting these distinctions on the routinier and change agent gives the following overview.

From the previous sections it becomes clear that an organization not only needs just routiniers or just change agents, it requires both. This fits in the concept of the ambidextrous organization by Tushman and O'Reilly, where innovative and stable operation is in balance [Tushman & O'Reilly 1996]. Although organizations can move through a phase where the role of the change agents are more pronounced, the routiniers are required to maintain the continuity of the organization while the organization is subject to a radical change. Once back into the recurring phase the role of the routiniers is more pronounced, but change agents can monitor new developments and identify new opportunities, which lie outside the current activities. The ratio between routiniers and change agents is not required to be equal; especially a more mature organization will have an emphasis on the recurring phase in order to optimize the revenues and profits. It is beyond the scope of this research to determine whether the routinier role and change agent role can be interchanged within an individual, but assuming that this is not the case, or not easy to achieve, the organization should maintain a balance between routiniers and change agents. This balance should on the one hand secure the efficient operation of the organization, even when it has to cope with change processes, and on the other hand enable paradigm shifting phases that can put the organization on a more sustainable growth path. It is hard to estimate what the proper ratio is of the routiniers and the change agents and may range from a 90-10 ratio for a mature organization in relatively static technology environment to a ratio of 10-90 for a technology startup.

A technology intensive organization comprises in general of multi-disciplined teams, requiring high levels of communication in order to develop and manufacture technology intensive products. A change of technology impacts at least the core of the organizational processes. Either the product will be manufactured in different ways or

the product has different characteristics, or both. These changes require a CFR which propagates through out the organization and which (hopefully) sticks to all stake holders.

This propagation process is an important process which requires management attention. It is not just about communication; it is about managing the impacts on the organization in general and the impact on the subdivisions in particular. Communication is not enough as the CFR of every individual subdivision that is affected by the change needs to be converted to a new CFR. As explained before this process is difficult and time consuming though very important in order to gain efficiency along the new paradigm.

8.10 Organizing Technology development

The embedding of technology development in an organization is for most organizations not very explicit. Large companies can afford to operate a dedicated industrial research laboratory, which executes research programs which provide technological options. Even within the industrial research organization, technology development is not necessarily an organizational identifiable entity.

In the field of innovation there are some contributions discussing the influence of the organisation form. For example Pettigrew et al. argue that the increasing global competitive pressures require more flexibility, less management costs, while sophisticated development and application of intellectual capital is required [Pettigrew & Fenton 2000, p.279]. The main notion is that professional service organization seems to form an archetype for modern organizations as professionals are associated with the creation of new knowledge and provides a high problem-solving potential.

Pettigrew et al. note that the organization form should somehow accommodate the multiple dualisms that are very relevant for innovation and economic activity; e.g., the exploration and exploitation, decentralized vs. centralized, network oriented vs. hierarchic. Jelinek and Schoonhoven found that large electronic firms strive to organizational forms that mimic small organizations, as it is believed that this promotes innovation [Jelinek and Schoonhoven 1990, p.19].

It is an activity that takes place at the interface of the research laboratory and the user, e.g., a business unit organization. Large and middle sized technology intensive organizations recognize the relevance of technology by appointing a Chief Technology Officer (CTO). In middle sized organizations, the CTO seldom has the mandate to execute technology development programs and more often can be seen in an advisory role rather than an executive role. In general, the organization of smaller TIOs does not have a dedicated identifiable organizational structure for technology development. It can be argued however that the smaller TIOs are formed around technology development activities as it is often the reason of existence of the TIO.

The role of the government is relevant for the technology development in TIOs. Governments recognise the importance of Research and Development in relation to economic growth and have incentives in place to stimulate investments in new technologies. These incentives are often based on tax incentives, but can also be formed around dedicated programs. In some countries the government involvements reach much further; dedicated spearhead programs are initiated to stimulate economical activity in certain technology areas. For example the Japanese MITI initiates very strong spearhead programs that have a large influence on R&D spending in the private sector by means of a government controlled inter-linkage of R&D capability within a focus area; so-called Keiretsu [e.g., Harryson 1995]. The idea is that organizations apply for funding by proposing development programs that fall within the spearheaded areas. Another practise, also observed in both Canada and The Netherlands, is that government funded research organizations develop technologies which can be transferred to small organizations and technology start-ups with the expectation that these organizations develop themselves towards middle-sized or even large size Technology Intensive Organizations.

In the US the importance of facilitating technology developments in order to realize economic growth is fully recognized. This importance result in policies that comprises of various funding instruments, covering not only general purpose (e.g. by means of National Foundation for Research (NFR) grants) but also more specific or, funded programs are often centred on strategic technologies (e.g. by means of National Institute of Health (NIH) grants). Branscomb and Keller give a detailed overview of the successes and failures of the US science and technology policies [Branscomb & Keller 1998].

Another example of specific funded programs is the funding structure of Defence Advanced Research Projects Agency (DARPA). DARPA is an organization which funds high risk technology development programs for Defence and Security purposes. These programs are selected on their potential impact, although it is recognised that the risk of failure is significant. DARPA funds technologies in the lower range of the technology readiness level (see Table 7.3). It typically works with a stepwise approach in terms of funding amounts and the corresponding goals; it starts for example with a so-called seedling program that delivers a demonstration of certain principles and typically gets limited funding.

A positive outcome can result in a new program that delivers a dedicated prototype device with a funded budget that is an order of magnitude higher. Such an outcome here can result in a program that brings the technology into production with a funding of again an order of magnitude higher. A funding organization like DARPA can indeed point at successes that truly provided new-to-the-world technologies that had large impact and which created large economical activities worth much more than the investments. However, DARPA's budget of in the order of a billion dollars per year is something that only a few countries can afford.

Chapter 8: Towards Managing CFR

Although government funding is very important, it is often subject to a debate of how effective the funding is and whether it is a waste of public financial resources. Assuming that technology development has a success rate of 10-15%, it is not surprising that many funded programs will lead to failure. Still, with returns on investments that can easily exceed a factor of 15, the reward is high.

Collective Frame of Reference in Technology Developments

“Managing technology development is so difficult!”²²

Chapter 9: Conclusions, Discussion and Reflection

In this Chapter the conclusions, the discussion of the results and the reflections are given of this study. This will be based on the research questions stated in Chapter 1 and the assumptions and hypothetical questions of Chapter 5. Based on these elements an overview is given of what can be concluded concerning technology development, paradigm shifts and the role of the collective reference. In the discussion section of this Chapter, this work is discussed in light of other findings in several ‘key note’ publications. Based on this discussion the contributions, limitations and recommendation for further research are given in a separate ‘reflections’ section. In this section the hypothesis will be discussed together with other recommendations for further research.

9.1 Conclusions

Based on the research questions, formulated in Chapter 1, the conclusions of this research will be given in this section. A discussion of these conclusions is given in the next section, where the conclusions are put in perspective of several relevant publications.

The first research question formulated in Chapter 1 is:

What are the characteristics of the technology development process in general and in comparison to the product development process and scientific discovery?

In Chapter 3, a description of the technology development process is given and the TO-model is presented. This TO-model provides insight into how the technology development process is positioned between scientific discovery and the product development process. Scientific discovery can be seen as a front-end for technology development, especially for modern technologies. Except for the empirically generated technologies, a scientific discovery provides a functionality that is useful to exploit. Science itself will not drive developments in order to enable exploitation; science is driven by the desire to deeply understand the phenomena and not by whether the phenomena can be used to the benefit of the society.

The activities within the technology development process are focussed on the exploitability of the functionality, and understanding the phenomena is, in contrast to science, not driven by a desire for knowing why but driven by knowing how to isolate and optimize the functionality. At the back-end of the TO-model, the technology

²² Quote from C.Draijer after completing this thesis

development process serves as a front-end for the product development process, where the functionality is incorporated in products, which serve certain needs in society. The technology options - generated by the technology development process - form platforms on which several products will be based. Therefore, technology options have a longer lifetime than the products and technology developments take in general much longer and are less frequent than product developments.

With respect to the characteristics of the technology development process and the differences with scientific discovery and product development, it can be concluded:

- The technology development process is positioned between the scientific discovery process and the product development process; it carries aspects of both processes and serves as an intermediating process transforming scientific knowledge in to products.
- Scientific discovery forms the front-end of the technology development process, while product development forms the back-end of the technology development process.
- A technological option is an artefact or construct that is often based on a scientific principle and which can provide a certain function. A product contains one or more of these technological options that are responsible for a specific function in the product.
- Based on the TO model, a technological option is passing through four phases:
 - o A generation phase where an artefact is created, and which shows certain functionality.
 - o A selection phase where the functionality of the artefact is competing with alternative options and where the particular benefits of the option are directed towards certain application areas.
 - o An integration phase where a specific option and its functionality is integrated with other options.
 - o A deployment phase where the option is incorporated into a product in order to provide this product with certain functionality.
- Technology, like science develops along paths, governed by a paradigm, which provides evolutionary, more or less predictable improvements, punctuated by developments leading to new paradigms. These paradigm shifts are unpredictable and have a revolutionary character, leading to radical change.
- The paradigm character of technology plays not only on a macro- and mesoscopic scale; it is also present within Technology Intensive Organizations. This paradigm character of technology developments in a Technology Intensive Organization, give rise to an organizational path dependency. Consequently, an organizational technology paradigm shift results in radical changes in the organization.

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- Radical technology development is a 'high risk - high reward' activity with a success rate of 10-20%.
- Radical or paradigm shifting technology development programs are hard to manage, unpredictable and require particular measures to weather short-term vs. long-term deliberations.

The second research question that is formulated in Chapter 1 is:

What are the processes and drivers at several levels in the organization, prior, during and after a technology path change?

The notion that 'normal' technology developments evolve along a path or follows an existing paradigm and that radical technology developments coincide with a paradigm shift is important here. As explained in Chapter 6, the Collective Frame of Reference in an organization provides focus on technology development along the existing paradigm that was previously chosen. Following the existing path or paradigm can be seen as an efficient way of developing technology; it is incremental, more predictable and can be planned reasonably well. These developments are covered under type A, B, C and D in Table 8.1.

In general these types of developments can be covered under pre-product development as proposed by Boersma as it is more challenging than product development. However, the problems which need to be solved are reasonably well defined and there is a high probability that a solution will be found. This research concluded that when members in the organization start to believe that the evolving technology development can no longer be maintained, the Collective Frame of Reference breaks down and eventually may vanish. This initiates a phase of reorientation, where alternative paradigms are identified, studied and evaluated. A new Collective Frame of Reference is created, allowing the organization to make a decision to proceed with a new paradigm from which it is believed it is better suited to serve the organization in its strive for continuity and sustainability.

Such a process can take many years as in some cases it takes an organization many years to explore a new paradigm and to build up a new CFR that becomes mature enough to base a decision on. Obviously, a change in a technology paradigm has an impact on many, if not all parts of the organization. This implies that a new CFR that gains momentum in the R&D department has to propagate not only vertically to the decision makers of the organization and/or vice versa, but also laterally to other parts of the organization that sooner or later will be affected by the change.

The propagation process is foregoing a change process in every part of the organization that is impacted by the new technology paradigm. The change process can take years before every part of the organization is shifted to an operation in accordance with the new technology paradigm.

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With respect to the driving forces that play during a technology path change in several levels of the organization, the following can be concluded:

- Technology development can be characterized as 'evolutionary' if it progresses along a technology path. Along this path a particular technological option is further developed and optimized for sequential product generations. The variability is limited and bound by the technology option.
- Technology development can be characterized as 'revolutionary' or 'radical' if it requires a paradigm shift. This paradigm shift implies that a current path is left and a technological option on an alternative path is selected and further developed. A paradigm shift comes with changes in the organization.
- Both the evolutionary and revolutionary technology development in the organization is driven by the Collective Frame of Reference; a sustained CFR provides an equilibrium state which directs the focus of the organization on the current paradigm and drives the evolutionary technology development, while a deterioration of the CFR leads to a punctuated state, which turns the focus of the organization to a reorientation phase where new paradigms are considered and revolutionary or radical technology development is initiated by adopting a technological option that is part of a new paradigm.
- A paradigm shift starts from and results in a recurring, cyclical phase, which represents an equilibrium state of the organization. The actual shift takes place in three phases; the reorientation phase where the organization identifies new technology paradigms to consider and start acquiring knowledge of paradigms that are thought to be suitable to provide useful and relevant technology options. In the second phase the organization takes all the decisions that are required to adopt the new paradigm. And in the third phase the organization implements decisions that have been made.
- The development of the CFR changes throughout the paradigm shift; in the recurring or cyclical phase the CFR drives the focus on recurring tasks that develop the current technology option. This recurring stage is an equilibrium state within the organization; the organization developed routines and knowledge that allows executing those recurring tasks in an efficient way. Due to several factors the CFR can break down and disappear, which may lead to a change of paradigm.

Research Question 3 has been formulated in Chapter 1 as follows:

How are alternative technology-paths identified, evaluated and selected?

Based on limited evidence, the study shows that new roads are found by individuals who no longer conform to the existing CFR of the organization. This individual basically loses focus on the paradigm that is followed, and diverts her/his attention to

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alternative paradigms. It is fair to say that the motivation for this non-conforming behavior is not necessarily based on objective considerations with the well-being of the organization in mind, but can originate from personal, highly subjective beliefs that are becoming different from the shared beliefs of the organization.

Initially this non-conforming belief is confined to the mind of the individual, but once this individual starts to share her/his beliefs, there is a chance that others will alter their beliefs in coherence with the non-conforming individual. Obviously, the new paradigm needs to inhabit certain reason in order to make it an alternative consideration for the co-members of the organization. Also, this is not happening in just a single event and it will take time to settle in the minds of co-members. The propagation of the new frame of reference is dependent on the co-members of the organization, as these co-members basically determine whether the new non-conforming belief is worth to consider.

This process has some very interesting aspects as it serves like a variation and selection mechanism; it is assumed that a variety of non-conforming beliefs are transmitted in the organization and that the co-members willingly or unwillingly 'select' beliefs that are sensible enough to consider. This selection is not a rational process - not only because beliefs are subjective but also due to relational aspects matter like personal favors, status of the non-conforming individual, etc.

In general, this non-conforming belief needs to gain momentum before it is considered as a factor in the organizational context. This is required in order to initiate exploration of the new paradigm and generate knowledge that feeds the decision process. In the context of a technology paradigm shift, this is painstaking work and requires time. The decision process is often a distributed process, where several decisions on aspects are taken in a sequential fashion. Consequently, the selection of alternatives is not driven by a single event, but a chain of events where multi-disciplinary knowledge is gathered on several aspects of the alternative paradigms.

Again, based on the limited evidence of this study, with respect to the identification, evaluation and selection of alternative technology paradigms or paths, the following can be concluded:

- The breaking of the technology paradigm is assumed to be sparked by an individual who develops a belief that opposes the shared belief that keeps the organization on the current technology paradigm. The origin of this non-conforming belief can be highly subjective and personally motivated.
- Once this individual is confident to share her or his beliefs with others, these beliefs may or may not be accepted by others. This is like a variation and selection process; the organization is exposed to a variety of non-conforming beliefs, while the other members reject or accept the non-conforming belief, and therewith determine whether a non-conforming belief propagates or fades out in the organization.

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- If the non-conforming belief holds and gains foothold with the decision makers in the organization, a wider reorientation process is initiated to obtain knowledge about alternative technology paths. This knowledge is required to make an informed decision about migrating to the new technology paradigm and involves many disciplines within the organization. This reorientation process involves other organizations as well, for example suppliers, technology partners and (potential) customers.
- The selection of an alternative technology paradigm is in general not a single decision point, but consists of a chain of decisions on sub aspects of the transition. In some cases several technological alternatives are studied in parallel and the selection takes place on benchmarking the technological options side by side (see, e.g., dialogue box 7.1)

Research Question 4:

What are effective management techniques to manage the organizational changes related to a technology path change?

Technology development is hard to manage and it is different from product development. From this study it can be concluded that one of the reasons that technology development is hard to manage is due to the fact that it involves individual beliefs and collective frames of reference. Both cannot really be managed by direct methods and actually can only be influenced by conditioning rather than by direct interventions. A most likely unpopular result of this study is that it is sometimes good if individuals develop beliefs that are misaligned with the CFR, and in effect no longer contribute to the goals that the organization has set.

Organizations are controlled by hierarchical management structures that rely on missions, strategies and goal setting and the expectation that the members in the organization strive to realize these goals is basically embedded in the CFR. Still, this non-conforming behaviour provides openings to break the path dependency at times when the path becomes harmful to sustainability of the organization. This latter remark is important; another most likely unpopular result of this study is that in the context of technology development, path dependencies are beneficial for the organization, as they allow for developing routines that improve the efficiencies and to harvest the investments that have been done to arrive at the path.

It is, however, also recognized that the organizational rigidities that come with path dependencies result in organizational inertias that make it very hard to break out of the path, even if it is threatening to the existence of the organization. The bottom line of this complex mechanism and its management is that the organization has to perform a balancing act between setting the conditions to operate efficiently along a paradigm on the one hand and setting the conditions to enable transitions to other paradigm.

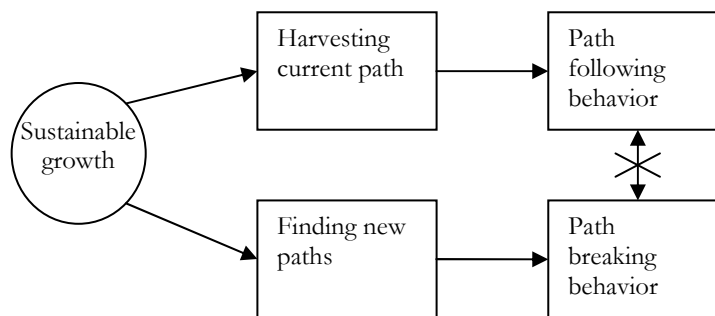
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Unfortunately, there are no straightforward management tools which guide decisions in this dual environment (see dialogue box 9.1).

It may be disappointing that the conclusion is one in which the combination of path breaking and path following behaviour can only be managed indirectly and that it has to rely on hard-to-catch phenomena like self esteem, interpretations of the organization's history, the culture and many more 'soft' factors comprised in the CFR. On a positive note it shows why management of technology is really difficult and that there are no obvious solutions or tools that can break open the organization, doing the right thing at the right time. Having said this, the management of the organization cannot do much more than carefully monitor the progress of the current technology

Dialogue box 9.1: Can the Theory of Constrains help here?

The Theory of Constrained (TOC) tends to deal with problems that have a dual character [Goldrath 1997, Goldratt & Cox 1986]. In this case the organization is required to find the balance between following a path and breaking with that very same path. In the so-called problem cloud (see below) a conflict appears that if the objective is to obtain sustainable growth, it is required to harvest the current path as it capitalizes on investments in the past, while it is also required to find new paths to secure growth on the longer term. Those two requirements result in a set of incompatible prerequisites: Focusing on the current path and leaving the current path.



and make attempts to condition both the CFR and non-conforming behaviour in a timely fashion in such a way that the paradigm shift takes place at the right moment: Not too early, not too late.

In this research, the CFR has been measured by registering the reactions on propositions that were related to technology. These propositions were both formulated positive and negative. This showed the dynamic of the CFR during workshops concerning technology decisions. This monitoring of the CFR in organizations can help management to understand what the state is of the CFR.

Aside from this measurement of the CFR, management can condition the CFR and non-conforming behaviour by influencing the following aspects:

- Gathering and providing objective information: Managing the flow of information is considered a very important factor to influence the CFR. The interpretation of information can either reinforce or weaken the beliefs of the organization and providing a flow of objective information can both reinforce the CFR and weaken the CFR, depending on whether the information contains conflicting or supporting elements of the existing CFR. Provided that the information is objective, both responses can be seen as positive; if an organization finds that there is a disconnection between the reality and the current beliefs it will not be sustainable and requires change. On the other hand, if an organization finds evidence that the current beliefs are in line with the objective information, this will strengthen the CFR.
- Connecting to the external networks is important, not only because it can provide objective information as discussed above, but also because it provides access to external knowledge in that is or will become important for the reorientation process. Assuring that the members in the organization are well connected to these external networks influences the CFR within the organization.
- Stimulate Confidence is important for the balance between the CFR and non-conforming behavior. Celebrating successes is important to focus on best practices. It is however argued that the failures need some attention as well. The failure rate of technology development is 80%-90%, which is extremely high, which makes it hard to base a self-confidence organization on. The appetite in the organization can diminish quickly, if the failures are highlighted in the organization.

The often heard phrase “not another disaster”, shows that a barrier is created towards similar developments, while often there is not a real understanding of what went wrong. Fact finding and communicating to the organization what contributed to the failure helps in threefold. Firstly, if real mistakes have been made, the organization learns from it; failures are generating knowledge as well. Secondly, it can place the failure into a perspective with a better understanding of what happened and why it happened, which adjusts the risk perception of the organization. Thirdly, a better understanding of the failure, allows for a better plan for success the next time.

- Allowing non-conformist behavior as it is a source of change in the organization. It is important to create an organization where non-conforming behavior to induce change and a mature CFR to harvest on existing technology coexist. This can be realized to pick up non-conforming behavior in a timely

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manner and nurture it in a structure that it allows to develop and does not disturbs the existing operation.

Once the organization has accepted the possibility of an alternative paradigm as a reality, there are tools available which can help to structure the data of the alternative technology paradigms. One could describe these tools as reorientation tools, which comprise trend analysis, correlation matrices, technology maturity analysis, etc. There is no magic to these tools and the general rule of modelling “garbage in = garbage out” applies here as well.

With respect to the management of alternative technology paradigms the following can be concluded:

- The management of the technology paradigms relies on indirect methods that conditions the CFR on the one hand and facilitates non-conforming behavior on the other hand.
- The CFR can be monitored to a certain extent with a preposition method where prepositions related to technology are presented to a group involved in technology development. The responses indicate the state of the CFR within the group and differences between groups.
- The management ‘tools’ to condition the CFR and non-conforming behaviour are based on providing objective information, connect to external networks, manage the confidence level of the organization by celebrating successes, analysis and communicate failures, plan for success, manage risk perception and create structures to facilitate, protect non-conforming behaviour.
- For the reorientation phase, structuring tools can be used that help to organize the data that is gathered in the reorientation phase. These tools comprises Technology Strength, Weakness, Opportunity, Threat analysis (Technology SWOT), Correlation matrices, DESTEP technology trend analysis, Technology Maturity analysis, Technology gap analysis, Net Present Value financial analysis and to Technology Partner analysis.

9.2 Discussion

9.2.1 The merits of the Collective Frame of Reference

In Chapter 7, the Collective Frame of Reference and its connections to literature as well the relationships to the Technology Development Process and Organizational Path dependencies have been discussed in some detail. Still, it is appropriate to discuss what the merits are of the concept of Collective Frame of Reference. With some

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confidence it can be said that CFR plays a role in organizations. This confidence is based on the in-depth study of the case studies presented in this dissertation, although it can be argued that this evidence is thin due to the limited number of cases. That the number of cases is very limited is a consequence of the fact that the study focuses on observing underlying processes in-depth, which almost seem to result into a paradox similar to Heisenberg's Quantum Mechanical uncertainty relations (see dialogue box 9.1). Studying processes in-depth reduces the confidence that what has been found can be generalized.

This confidence can partly be established by a literature study to look for similar elements and concepts. This is reported in Chapter 7. Another way is to conduct quantitative research, where the details found in the in-depth study are specifically addressed in larger scale surveys and interviews. This latter does not fall within the scope of this study, but it forms the main recommendation for further research. The literature study in Chapter 7, together with the empirical findings from the case studies, is the basis on which the existence and relevance of the concept of Collective Frame of Reference is based. As this is an important issue, it helps to provide an overview of this data. Table 9.1 summarizes the evidence for and relevance of the concept of CFR.

Concept in Literature	Authors	Rational for CFR	Evidence	Relevance
Paradigm	Kuhn	The notion that paradigms are followed collectively in an equilibrium state and that punctuated paradigm shifts are initiated by individual efforts, in times of a crisis. The presence of the CFR applies a collective focus on following a paradigm, while the absence of the CFR mobilizes individual efforts to find a new paradigm.	The evidence is mainly based on the patterns that have been observed in case study C.	The CFR provides an explanation of the mechanism to shift from equilibrium, evolutionary, focussed mode of operation to a punctuated, revolutionary, defocused mode of operation.
Technology Paradigm, regimes	Dosi, Nelson, Winter, Marsili	Technology paradigms have been brought in connection with the scientific paradigms (see above) and Technology paradigms do exist within the organization.	The taxonomical breakdown of technologies in a product as presented in Chapter 3 make it plausible that technology paradigms do exist within organization.	The notion that technology paradigms exist within the organization and that paradigms shift according to the process described by Kuhn (see above) connects the CFR to technology development

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Routines	Nelson, Winter	An organization in equilibrium relies on routines. A mature CFR constitutes in the development of these routines.	There is no direct evidence that brings routines in connection with the CFR. It can be made plausible that as both the presence of a CFR and routines are related to evolutionary developments	This is relevant for the CFR in the context of Technology development. In evolutionary technology development, dedicated problem solving routines are used to make incremental progress. These routines are embedded in the CFR.
Dynamic Capabilities	Teece, Salvato	The dynamic capabilities are 'learned and stable patterns of collective activity', which are created under the presence of a stable and consistence CFR. The reforming the dynamic capabilities rely on individual factors rather than collective factors (Salvato)	There is no direct evidence that brings dynamic capabilities in connection with the CFR. Again it can be made plausible that the capabilities are embedded in the CFR and that the change of these capabilities happens in a individual way (not bound by a CFR)	Same as the routines discussed above.
Path dependency	Sydow et al	The presence of a CFR constitutes in path dependencies and the absence of the CFR results in path-breaking efforts.	Identifying path dependencies with following a paradigm makes it plausible that path dependencies and CFR are related. Elements to cope with in order to break paths are found to constitute in CFR.	The confirmation that CFR plays a role in organizational path dependencies, results in a broader applicability of the CFR.
Cognitive Distance	Nooteboom et al.	Constitutes perceptions, proprioception, sense making, emotions,(value judgements and even feelings)		
Images	Dougherty	The absence or a weak CFR creates the inability to coordinates the actions of actors in the technology development process.	There is no direct evidence that the CFR and organizational images are related. Interestingly, in the initial phase of the study towards CFR, the sensitizing concept was based on 'images'.	If the CFR incorporate the organizational images as defined by Dougherty, it allows relating CFR to organizational learning.

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Knowledge-ability	Orlikowski	Like CFR, Knowledgeability is presented as the ability to drive action, and which is highly dependent on the context, agency and structure. It is a capability that can guide collective efforts and it is fluid, virtual and provisional.	Based on the empirical evidence presented in Chapter 4 and 6, it seems that CFR is driving collective efforts and that is fluid and provisional. This suggests that CFR constitutes in knowledgeability	The essence of CFR is that it drives collective efforts (and it absence drives individual efforts)
Shared identity and organizational identity	Kogut, Zander, Dutton, Dukerich	Like CFR, the shared identity provides a sense of community by which discourse, coordination and learning is structured. And a shared set of beliefs about what the organization is.	CFR has been identified by shared beliefs, which would link it to the shared or organizational identity	The factors comprised in shared or organizational identity, are related to lead to path dependencies.
Reconceptualization	Tsoukas	Tsoukas relates this reconceptualization to three process; Conceptual Combination, Conceptual Expansion and Conceptual Reframing.	There is no direct evidence to relate CFR to Reconceptualization, other that the condition under which the CFR will change and the occurrence of Reconceptualization seem to be very related	The relation to CFR is not very obvious, although it is expected that non-conforming individuals interact with other members in the organization to 'promote' their alternative ideas. It is expected that the dialogue process plays a role in the propagation of new CFRs
Deep structures	Heracleous and Barrett, Gersick	Like the CFR, the deep structure represents the forces that keep actors moving along an existing paradigm, rather than considering a new paradigm.	The CFR has been related to the deep structure, but the CFR has been though to be more fluid. There is no direct evidence also because the CFR has been observed in a situation where there was an evident need to change.	It relevance is that a persistence CFR driving the actions and interpretations of the actors, which is hard to change
self-reinforcing forces	Sydow	Similar to CFR, the self-reinforces forces constitute from (a) emotional reactions like, e.g., uncertainty avoidance and inter-group revenge, (b) cognitive biases like, e.g., selective perception, blind spots, implicit theories, and (c) political processes like, e.g., gaining power, maintaining power, and reciprocal negotiation.	No direct evidence, although many elements that apparently constitute in self-reinforces forces, are related to CFR in Chapter 5	CFR is seen as instrumental to focus the organization to progress along the path, which implies that the self-reinforced forces are related to the CFR.

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Collective sense making.	Santos and Eisenhardt,	organizations, state that organizational members actively participate in the and through this sense making, information is filtered, historical interpretations and the meaning of external influences are shared, and guidance for actions is provided. Furthermore, it is noted that “sense making tends to crystallize into cognitive frames that reduce ambiguity and facilitate decision making” and It is apparent that cognitive frames and cognitive coherence, in relation with decision making and guiding activities, link directly to CFR	“Once cognitive frames are developed, they create cognitive coherence and guide subsequent actions”. [Santos & Eisenhardt 2005, p.500].	
Group think	Janis, Baron	The CFR ‘gone bad’: which is based on: <ul style="list-style-type: none"> - Social identification, which represents the extent to which the group members feel connected to the group, by a common purpose, shared belief or common history. - Salient Norms, which provides a group-polarization that influences the group decisions. - Low Self efficacy: which results in a lack of confidence that a solution can be found. 	No direct evidence, other that Groupthink can be identified as a special case of CFR, where a persistent CFR leads to catastrophes.	CFR needs to be sufficiently open for new information. With a mature and open CFR a group will both be able to stay on course as well as to make reasonable decisions on when to reorient.
Mindsets	Zyphur	Similar to CFR, a mindset is defined as a routinized mode of thinking which exhibits a certain path dependency and recognizes that switching of mindset is difficult.	No direct evidence, but mindset contains elements like routines, which have been direct or indirect related to CFR	This seems to be related to the CFR, where for example certain problem solving techniques prevail over others as they have been proven in the past and because the techniques matches the kind of problems that are associated with the current paradigm.
Collective mind	Weick, Roberts	The collective mind relates partly to CFR in a way that prescribed procedures can create a situation where the acting is determined by these procedures.	No direct evidence, the collective mind seems to be a specific form of the CFR, where the CFR is build-up by complex procedures.	This collective mind seems to suppress individual interpretation and acting, within a predefined framework. In technology development this framework is missing, but it shows that it is possible to create a situation where actions of individuals are driven by a framework.
collective sense making	Weick, Santos, Eisenhardt	Similar to CFR, organizational collective sense making relates to collective actions. This collective sense making leads to path dependencies like CFR does.	No direct evidence, although collective sense making seems to comprise the spirit of CFR found in this study.	The patterns of the creation and destruction of the CFR, refers to a situation where the collective sense makes no sense anymore.

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Teleological problem solving	Das, Van de Ven	The CFR plays a role with collective problem solving. The teleological stream is based on the assumption that movement can be guided towards a certain goal or end state.	The evidence is based on the case study in Chapter 4, where a group of scientist envisioned a goal and worked towards this goal with fundamentally different methods (paths)	It assumes an envisioned end state, as captured in the CFR, resulting in actions with the intention to reach the end state and monitoring the progress.
Tacit knowledge	Polanyi	Tacit knowledge is like CFR responsible for collective knowledge generation. Where tacit knowledge suggest that it is justified and true, this is actually hard to proof as long it is tacit.	No direct evidence other than that tacit knowledge can be identified with unjustified belief, which is related to the CFR.	CFR is a form of unjustified belief, which is not necessarily explicit. A CFR can after verification constitute in knowledge, but again this is not necessarily explicit and can become tacit

Table 9.1: A table with summarizing the embeddedness of the concept of Collective Frame of Reference in literature and the evidence found in this study.

The number of entries in Table 9.1 shows similar concepts and elements of the CFR are widely described in several bodies of literature. Although this may not directly add to the merits of the CFR, it shows at least that the CFR and its elements are embedded in literature. It is hard to prove for all these concepts that there is an evidential connection to the CFR. From another perspective however, one could argue that the fact that the CFR seems to be related to such a large number of concepts, provide some confidence that the CFR is a useful addition to the already wide spectrum of reported concepts. One could see this as a merit of CFR.

Although the basis to claim that the CFR is ‘measurable’ is thin, at least in this study a technique has been used that suggested that the CFR could be probed and registered. So far it seems that this has not yet been reported and this can also be seen as a merit of the CFR.

The dynamics of the CFR provides some unique features; it shows that the CFR is not a given, it is dynamic and it seem to explain in literature established process like path dependencies, punctuated equilibriums and evolutionary and revolutionary or radical developments. This is also a merit of the CFR.

Again, a study based on limited case studies implies that generalization of the results seems impossible (see dialogue box 9.1), but by showing that several published papers touch on similar phenomena, provides some comfort.

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9.2.2 Management of Technology Development

Cooper points at the crucial decision moments especially in the beginning of the technology development process, while the TO-model deals with the development stages of the technology options rather than with the process flow of the development. The two processes are not necessarily incompatible and actually could be applied simultaneously.

A difference is that the TO-model assumes that a technology option has to reach a certain state of development before it can be implemented and that this is part of a selection process where several technological options can be considered to provide the functionality in a product. This process is not (specifically) described by the stage gate process. A weakness of the TO-model is that it does not deal with specific decisions although it is clear that underlying decisions have to be made.

The question is, however, whether adding resolution to the model with respect to the specific decision actually contributed to the manageability? The (somewhat naïve) assumption in this research is made that once the organization has made the choice to

Dialogue box 9.1: Heisenberg's Uncertainty relations, in-depth studies and generalization

The Heisenberg Uncertainty relation describes the inherent inability to determine the position and momentum of a particle simultaneously. This implies that when the position of a particle is well defined, the momentum is uncertain and vice versa. Hence the uncertainty relation is given by:

$$\Delta p \cdot \Delta x = \hbar$$

Where \hbar is taken constant. A well defined position will require that Δx is small, which is only possible if Δp is large, or not well defined.

In relation to in-depth studies and generalization, the following uncertainty relationship seems to apply in analogy to Heisenberg's uncertainty relation:

$$\Delta D \cdot \Delta H = C$$

Where C is taken constant. A in-depth study where processes are studied in great detail, i.e., ΔD is small, the heterogeneity ΔH becomes large and vice versa; if the heterogeneity between organization should be small, the ΔD will be large, i.e. not much detail can be added. It is assumed that $H=1/G$, where G is the generalization. Interestingly, there are two main factors contributing to this paradox. The first factor is the bandwidth of the researchers; an in-depth study takes a lot of time and it is impossible to do these studies in many organizations in order to make a firm statement concerning generalization. The second factor is that organizations are complex organisms, where you will find differences if you dig deep enough.

enter the technology development process with a certain phenomena (and therewith passed stage 1 and 2 of Cooper's model), it has to feed it with resources and monitor the progress in the development stage of the technology option. This provides management with a weak control over the process, but the issue with a stage gate process is that many crucial decisions are made by the researchers in this stage and those decisions are almost made on a daily basis.

In this perspective, the manageability of the technology development process is limited by providing resources and monitoring progress, rather than very distinct decision points. Actually, this is no different for an organization stuck for years in stage 3 of Cooper's model; which is the actual technology development process and which captures all the development stages of the TO-model. Sheasley [Sheasley 1999] also argues that the technology development process is fundamentally different from product development. Sheasley proposes to increase the effectiveness of the technology development process by cycle time management.

9.3 Reflections

It is appropriate to reflect on the theoretical framework described in Chapter 2 in relation to the findings, conclusions and discussion in this Chapter. The theoretical framework is based on the assumption that the technology development process is sandwiched between the scientific discovery process and the product development process and that the technology development process carries interpolative characteristics of the two outer processes. Although the validity of these assumptions has not been a specific research goal, it is fair to say that no evidence was found that this is a wrong assumption. The notion that the evolutionary economists [Nelson & Winter 1982, Dosi 1984] linked technology development to path-dependencies similar to Kuhn [Kuhn 1970], the early notions of Polanyi on Scientific beliefs and 'Invisible hands' pointed at driving forces in scientific discovery [Polanyi 1950, Polanyi 1962], while noting that technology development was not much different from Scientific discovery, and Simon's notion that science is practiced with generic, 'every day' problem solving routines; all pointed at the validity of an interpolation from the science side of the sandwich.

The framework of Brown and Eisenhardt offered enough elements to justify interpolation from the other side of the sandwich [Brown & Eisenhardt 1995]. In hindsight the theoretical framework served its purpose, but a more profound literature analysis in the first sections of this Chapter showed that socio-cognition elements are playing a much more prominent role than initially anticipated. In a way it was a joyful experience to read more recent publications on path dependencies [Sydow 2009], knowledge creation [Nonaka & Krogh 2009], organizational boundaries [Santos & Eisenhardt 2005], cognitive distance [Nooteboom 2007], and the link of individuals to

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dynamic capabilities within the firm [Salvato 2009], all dealing with the similar issues emerging from this work..

At a minimum it shows that the understanding of what happens in organization is still very relevant and it also showed that the phenomenon of organizational change is still not fully understood. Hopefully, this work offers some additional insights into this change process.

Organizational research Key issues according to Pettigrew 2001	Scale of applicability [0-4]	Comments
Multiple levels of Analysis	3	The study observed technology change process at the management and developer level
Time, History, Process and Action	3	The research is based a longitudinal study of technology development processes
Linking Process to outcome	1	A direct coupling has not been observed/measured towards the actual financial performance. Mainly because this is lagging many years.
International Comparative research	0	Although research has been done in a Dutch and Canadian context
Receptivity, Customisation, Sequencing and Pace	4	This research studied the CFR during the change process and the actions related to that.
Linking Scholarship and Practice	2	This research is conducted by a knowledge worker, deployed in the field, with a background in Physics. In this perspective it falls in a mode 2 knowledge production [Pettigrew 2001 p.705, Gibbons 1994]

Table 9.2: Reflection on key issues for studying Organizational Change according to Pettigrew [Pettigrew 2001]

The first and foremost question is whether the CFR does exist in the organization, and with some confidence it can be said that this question has a positive answer; it may be not so much based on the observations as these were done in only a few organizations, but mainly based on the evidence of similar organizational phenomena with similar or equal characteristics of the CFR.

Another important question is whether organizations can break with the path dependency. An important insight from this work is that if technology development leads to an intra-organizational path dependency, new technology developments within

an organization can only take place if the current technology paths are broken. Although this path-breaking process is not a daily practice, it happens at times and the many organizations that shift technology paradigms with their product lines show that it is a reality. What is more peculiar however is that in the organizational path-dependency literature the existence of path-breaking is still under question.

During the literature study, some publications were reviewed that provided conditions for research towards organizational change and path dependencies. Given the fact that both elements form an important element in this study, it is appropriate to reflect on these concepts. Pettigrew provided an overview of key issues for the study of organizational change. Based on these key issues, a qualitative benchmark of this study is been given in Table 9.2. As shown in Table 9.2, there are some areas that are not well covered by this study, but some areas seem to comply with some key issues that have been identified by Pettigrew.

More recently, Sydow provided recommendations for research of organizational path-dependencies. These recommendations are benchmarked in Table 9.3. The benchmark towards the recommendations of Sydow shows that this research has a good coverage with the recommendations.

Elements of path dependency research [Sydow 2009]	Scale of applicability [0-4]	Comments
Identification of strategic persistence	4	The moment of reconsidering the current technology path has been clearly identified in the main case (Chapter 6); based on a pessimistic view on the current technology, the organization decided to consider alternative technology options
Identification of self-reinforced feedback	3	During the research events were observed where actors in the organization tended to fall back to the existing CFR
Identification of trigger events and critical junctions, lock-in	4	This research studied the situation where an organization was breaking free from a path dependency, the critical events were noted and registered
Longitudinal research, tracing sequences of events and action in the organization	4	This research design was based on a longitudinal study, where moves and actions were registered (see Chapter 6)

Table 9.3: Reflection on the recommendation for studying Organizational Path-dependencies according to Sydow [Sydow 2009]

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Another angle to this research is the depth to which the technology development process could be followed. At the start of this study, it was argued that an in-depth study is useful as it will reveal the nuances of the processes in more detail. At the end of this study, this aspect has been confirmed, at least by myself and it was more encouraging to see that others provided results of research based on similar settings. From this perspective this study falls in a tradition of organizational research that is well phrased by Salvato: "..., I argue that understanding a firm's ability to systematically renew its strategy and underlying capabilities requires an in-depth understanding of the micro-processes that make up an organizational capability and its component routines.."

Salvato did spend four years at a single company, following 90(!) new product development processes [Salvato 2009]. The goal of this study aligns with the comment of Salvato; an in-depth understanding what happens in the technology development process, of which several have been followed in the period 1996-2010.

9.3.1 Contributions

In general, this research contributed to the notion that technology development is an important factor for sustaining organizations. This research also contributed to a more complete description of the technology development process, especially in the context of scientific discovery and product development. The path dependent character of technology development was known on a macroscopic and mesoscopic scale as described by evolutionary economics as proposed by Nelson & Winter and Dosi.

The paradigm character of technology developments within the organization has as such not been described specifically elsewhere. The notion that organizations are bound by previous technology decisions and that it requires considerable effort to deflect from the previously chosen path, showed that, especially the mid and small size technology intensive organizations, radical technology development is not always a choice.

The main contributions regarding the second research question is the notion that the Collective Frame of Reference is an organizational entity that drives the organization towards following a technology paradigm. Consequently the breakdown of the CFR results in a situation that other paradigms are considered and that a newly formed CFR allows the organization to focus on developments along a new technology paradigm. Table 9.1 shows that the CFR is related to at least 20 other concepts and elements that have been or still are discussed in literature.

On the one hand, it can be argued that adding another concept is not of much value. On the other hand however one could also argue that the CFR serves as a connecting element between all these phenomena. These connections are not necessarily proven, but from what is discussed in literature, there seem to be a connection. One of the

merits of the CFR is that it seems to explain how an organization follows a technology path and how the organization breaks with a current technology path. Also it seemed possible, with limited evidence though, to monitor the CFR during the change of technology paths.

The conditions for this path breaking have been discussed but the actual mechanism is still unrevealed. There is some confidence that this study sheds a light on these path breaking conditions. Linking the CFR to organizational path dependencies suggest that the concept of CFR is possibly wider applicable than only to technology development. The above presumed mechanisms and patterns needs more research, but hopefully defining the concept of CFR will help to apply some focus to these efforts.

9.3.2 Limitations

The limitations of this study are obviously related to generalisation and its qualitative character. This point is fully recognised, but the idea behind this study is to obtain a deeper understanding in the process of technology development activities within the organizational boundaries and observe and understand the processes that take place. This inevitably results in a subjective view, first of all by the bias of the researcher, secondly by unique characteristics of the organization, which potentially 'colour' the results.

The grand paradox of this study is that 'unjustified beliefs' of the researcher in combination with the collective 'unjustified beliefs' of the observed organizations may result in unjustified conclusions concerning unjustified beliefs. There may be some reason for optimism though: Firstly, the study is seen as a necessary step to focus on a sufficiently deep level in the organization to obtain understanding of the processes. The process of decisions on technology development could be observed at the level of the technology developers self, mainly because the researcher was able to participate and contribute to these processes. In this perspective the goal of the study is to provide understanding of the technology development process in order to allow more quantitative oriented research towards technology development across organizations, industries and countries. This activity is not scoped in the current set up, but as a 'service' to other researchers who hopefully are inspired to prove this thesis either right or wrong, some basic hypotheses are formulated to guide further recommenced research (see next section).

Secondly, there is a strong belief that the basic processes related to technology development activities do not differ much across organizations. This strong belief is mainly related on other studies with a cross organizational orientation, where differences are found in terms of decisions and outcomes, but not where the basic problem solving activities are not different. Between organizations, there are definitely differences in culture, levels of organizational self-esteem, previous successes and failures, and obviously different routines, but part of this study is exactly about these

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differences in the form of the CFR as a framework of unjustified beliefs that influence the decisions and sequences of the activities, but not the problem solving itself.

The main case study is executed in a semiconductor firm and one could argue that the results and conclusions are specifically applicable for firms in this industrial regime. Still, there is a belief that a TIO operating in a semiconductor regime may have to deal with other internal and external factors than for example a TIO that is operating in an automotive industrial regime [see e.g., Marsili 1999], but it is expected that the organizational processes are not so much different across the industrial regimes.

Thirdly, the findings regarding the technology development process have been verified by means of member checks. Aside my own experience in four R&D organizations, two experts with 25+ years of experience in 4-5 TIOs each were asked to verify the findings based on their experiences (See Appendix B) The findings were not deviating from the practises known by these independent senior experts. This however does not justify generalisation per se. A more widely oriented verification should be done in order to validate the findings concerning the technology development process.

9.3.3 Recommendations for further research

As explained in the previous section, further research is required to generalize the findings of this research. In this section, the initial assumptions and hypothetical questions from Chapter 5 are evaluated on the analysis so far and reformulated where required. Although it is not excluded that I will carry on with generalization of this work, there is an expectation and hope that other researchers will either reject or confirm the formulated hypotheses.

Based on the discussion in the previous sections of this Chapter, question 5.1 can be revised and defined more accurately within the context of the reviewed literature in the following hypothesis.

Hypothesis 9.1: A Collective Frame of Reference constitutes shared beliefs, values and emotions that provide a cognitive coherence and results in coherent distributed activities.

This hypothesis is linked to the notion of Santos and Eisenhardt [Santos & Eisenhardt 2005, p.500], where the equality of ‘cognitive frames’ and CFR is assumed. Also assumed is that beliefs, values and emotions constitutes to the CFR. The distributed activities take into account that a group, gifted with cognitive coherence, perform several different activities in a (self)-coordinated fashion.

Question 5.2 is related to the relationship between CFR and knowledge. The notion here is that the current leading idea is that knowledge generation may stem from social

practises [Nonaka & Krogh 2009]. In the context of this study a link of the CFR to knowledge generation may support this idea. This provides a specific problem to be addressed; if CFR is subjective and socially loaded, how can it constitute in 'justified true belief'.

The easy solution is to assume that CFR steers the problem solving process, by 'prescribing' the kind of problem that needs to be solved and setting the goal state of the problem solving routine. Once the problem is actually solved, and the solution can be reproduced and externally verified, the solution obtains a certain objectivity that constitutes in a justified true belief or knowledge. According to this reasoning, question 5.2 will be converted as follows:

Hypothesis 9.2: The CFR determines the choice of the problem solving routine and determines the goal state of the problem solving routine and consequently determines how the knowledge is generated and which knowledge is generated.

Question 5.3 is related to the volatile character of the CFR and refers to two cases that are related to the acceptance or rejection of Hypothesis 9.2. While acceptance of hypothesis 9.1 proves that the presence of a CFR positively correlates with coherent activity, the absence should prove that the activities become incoherent.

Hypothesis 9.3: The absence of a Collective Frame of Reference constitutes in a cognitive incoherence and results in incoherent distributed activities.

Question 5.4 is related to the propagation of the CFR through an organization, while question 5.5 questions the propagation of a vanishing CFR. Relevant to these

Hypothesis 9.4: The new CFR or cognitive frame propagates through the organization by the process of (dialogues) induced reframing.

phenomena is the work of Tsoukas on the role of dialogues on knowledge generation [Tsoukas 2005]. One of the dialogue induced knowledge generating mechanism that Tsoukas describes as a case of 'non-metaphorical reframing', where an individual 'reframes' of co-workers by posing an enlightened idea. This is very similar to a shift in CFR that has been observed in this study. In this perspective question 5.4 is rewritten to the following hypothesis:

While question 5.5 leads to the following hypothesis:

Hypothesis 9.5: A vanishing CFR or deteriorating cognitive frame propagates through the organization by the process of individual reframing.

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Finally, question 5.5 relates to individual frame of reference versus a Collective Frame of Reference. As discussed previously, an individual who no longer conforms to a CFR,

Hypothesis 9.5: An individual, who no longer conforms to an existing CFR will direct her/his activities incoherently to the activities that are guided by the existing CFR.

likely shifts from the Collective Frame of Reference to an individual frame of reference. Assuming that the CFR coordinates coherent distributed activities, the activities of the non-conforming individual is expected to become non-coherent with the coherent activities. This reasoning leads to the following hypothesis:

Stating these hypotheses at the end of this thesis is done with the intention offsetting a framework for more widely and quantitative research that I think is required to add more detail not only the Technology Development Process and the concept of Collective Frame of Reference, but also to add more detail to path breaking processes that are not well known yet.

Waterloo, April 2010

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References

- Adner 2002**, Adner, R., “When are Technologies Disruptive?”, *Strategic Management Journal*, Vol.23, 2002, p.667-688.
- Akao 1990**, Akao, Y. (Ed.), “Quality Function Deployment-Integrating Customer Requirements into Product Design”, Productivity Press, Cambridge, MA.
- Allen 1977**: Allen, T.J., “Managing the flow of technology” 1977, Cambridge, MIT Press.
- Amason 1996**, Amason, A.C., “Distinguishing the Effects of Functional and Dysfunctional Conflict on Strategic Decision Making”, *Academy of Management Journal*, Vol. 39, No.1, 1996, p.123-148.
- Ancona & Caldwell 1992**, Ancona, D.G., Caldwell, D.F. “Bridging the Boundary External Activity and Performance in Organizational Teams, *Administrative Science Quarterly*, Vol.37, 1992, p.634-664.
- Anderson & Tushman 1990**, Anderson, P., Tushman, M.L., “Technological Discontinuities and Dominant Designs”, *Administrative Science Quarterly*, Vol.35, 1990, p.604-633.
- Antonelli 1997**, Antonelli, C., “The economics of path dependence in industrial organization”, *International Journal of Industrial Organization*, Vol. 15, p.643-675, 1997.
- Antonelli 1999**, Antonelli, C., “The micro-dynamics of technological change”, Routledge, London, 1999.
- Argote 1999**, Argote, L., “Organizational Learning: Creating, Retaining and Transferring Knowledge”, Kluwer Academic Publishers, Norwell, MA, 1999.
- Argote 2003**, Argote, L., et al., “Managing Knowledge in Organizations: An Integrative Framework and Review of Emerging Themes”, *Management Science*, Vol.49, No. 4, 2003.
- Arthur 1989**, Arthur, W.B., “Competing technologies, increasing returns and lock in by historical events”, *Economical Journal*, Vol.99, 1989, p.116-131.
- Bain 1956**, Bain, J.S., “Barriers to New Competition: Their Character and Consequences in Manufacturing Industries, Cambridge 1956.
- Baker 1967**, Baker, N.R., et al., “The Effect of Perceived Needs and Means on the Generation of Ideas for Industrial Research and Development Projects”, *IEEE Transactions on Engineering Management*, Vol. EM-14, No.4, 1967, p.156-163.
- Balachandra 2004**, Balanchandra, R., et al., “The Evolution of Technology Generations and Associated Markets: A Double Helix Model”, *IEEE Transactions on Engineering Management*, Vol.51, No.1, 2004.
- Baron 2005**, Baron, R.S., “So Right, It’s Wrong: Groupthink and the Ubiquitous Nature of Polarized Group Decision Making” In Zunna, M.P. (Eds), “Advances in Experimental Social Psychology”, Vol. 37, 2005, p.219-253, Elsevier Academic Press, San Diego.

- Beckman & Burton 2008**, Beckman, C.M., Burton, M.D., “Founding the future: Path dependence in the evolution of top management teams from founding to IPO”, *Organization Science*, Vol. 19, 2008, p.3-24.
- Berends & Weggeman 2002**, Berends, J.J., Weggeman, M.C.D.P., “Kenni, kennisdefinities en kennismanagement”, in “Kenni en Managment, van Baalen, P., ed. Schiedam, Scriptum, 2002 (Dutch)
- Berends 2003**, Berends, J.J., “Knowledge Sharing in Industrial Research”, Thesis EUT, 2003
- Berry & Taggart 1994**, Berry, M.M.J. and Taggart, J.H., “Managing technology and innovation: a review”, *R&D Management*, Vol.24, No.4, 1994, p.341-353.
- De Boer 2000**, De Boer, M., “Management of Media-Morphosis”, Thesis Erasmus University Rotterdam, 2000.
- Bijker 1987**, Bijker, W.H., et al.”The Social Construction of Technological Systems”, MIT Press, Cambridge, MA, 1987.
- Boersma 1994**, Boersma, W.H., “Pre-development in Technology-Intensive Organizations”, Thesis Eindhoven University of Technology, 1994
- Borgatti & Foster 2003**, Borgatti, S.P., Foster, P.C., “ The Network Paradigm in Organizational Research: A Review and Typology”, *Journal of Management*, Vol. 26, No. 6, 2003, p.991-1013.
- Bowonder 2000**, Bowonder, B., et al., “R&D Spending Patterns of Global Firms”, *Research.Technology Management*, Vol.42, No.6, 2000, p.44-55.
- Branscomb & Keller 1998**, Branscomb, L.,Keller, M., (Eds) “Investing in Innovation”, MIT Press, Cambridge, MA, 1998.
- Broeder 1998**, Den Broeder, F.J.A. et al., “Visualization of Hydrogen migration in solids using switchable mirrors”, *Nature*, Vol.394, No.6694, 1998, p.656-658.
- Brown & Eisenhardt 1995**, Brown, S.L., Eisenhardt, K.M., “Product Development: Past Research, Present Findings, and Future Directions”, *Academy of Management Review*, Vol.20, No.2, 1995, p.343-378.
- Burgelman 2001**, Burgelman, R.A., et al., “Strategic Management of Technology and Innovation”, McGraw-Hill, New York, 2001.
- Busby 2001**, Busby, J.S. “Practices in Design Concept Selection as Distributed Cognition”, *Cognition, Technology & Work*, Vol.3, 2001, p.140-149.
- CBO 2007**, Congress Budget Office, “ Federal Support for Research and Development” CBO publication No. 2927, 2007
- Cheah 1990**, Cheah, H.B., “Schumpeterian and Austrian Entrepreneurship: Unity within Duality”, *Journal of Business Venturing*, Vol.5, No.6, 1990, p.341-347.
- Clark 1987**, Clark, K.B., et al., “ Product Development in the World Auto Industry”, *Brookings Papers on Economica Activity*, Vol.3, 1987, p.729-781.
- Clark & Fujimoto 1991**, Clark, K.B., Fujimoto, T., “Product Development Performance”, Harvard Business School Press, Boston, 1991
- Cooper & Kleinschmidt 1987**, Cooper, R.G., Kleinschmidt, E.J., “New Products: What Separetes Winners from Losers?”, *Journal of Product Innovation Management*, Vol. 4, 1987, p. 169-184.

References

- Cooper 1990**, Cooper, R.G., "Stage-Gate Systems: A New Tool for Managing New Products", *Business horizons*, Vol.33, 1990, p.44-54.
- Cooper 2006**, Cooper, R.G., *Managing technology development projects*, *Research Technology Management*, Vol.49, No.6, 2006, p.23-31.
- Christensen & Overdorf 2000**, Christensen, C.M., Overdorf, M., "Meeting the Challenge of Disruptive Change", *Harvard Business Review*, March-April 2000, p.67-76.
- Christensen 2002**, Christensen, C.M., "Rules of innovation", *Technology Review*, Vol.105, No.5, 2002, p.32-38.
- Das & Van der Ven 2000**, Das, S.S., Van der Ven, A.H., "Competing with New Product Technologies: A Process Model of Strategy", *Management Science*, Vol.46, No.10, p. 1300-1316, October 2000.
- David 1988**, David, P.A., "Path-dependence: putting the past into the future of economics, Technical Report, 533, The economic series, Inst. Of Mathematical Studies in the Social Sciences, Stanford University, Stanford, 1988.
- David 1993**, David, P.A., in Rosenberg, N., R. Landau, et al., Eds. "Technology and the Wealth of Nations", Stanford University Press, Stanford, CA, 1993.
- Dickinson 2001**, Dickinson, M.W., et al., "Technology Portfolio Management: Optimizing Interdependent Projects Over Multiple Time Periods", *IEEE Transactions on Engineering Management*, Vol.48, No.4, 2001, p.518-527.
- DOD 2006**, DOD Defense Acquisition Guidebook, 2006.
- Dosi 1984**, Dosi, G., "Technical change and industrial transformation : the theory and an application to the semiconductor industry", S.l. : MacMillan, 1984.
- Dosi 1988**, Dosi, G., "Sources, Procedures, and Microeconomic Effects of Innovation", *Jour. Of Economic Literature*, Vol XXVI, p.1120-1171, Sept, 1988.
- Dougherty & Heller 1994**, Dougherty, D. and T. Heller. "The Illegitimacy of Successful Product Innovation in Established Firms." *Organizational Science* 5(2): (1994) 200-218.
- Dougherty & Hardy 1996**, Dougherty, D. J. and C. Hardy, "Sustained Product Innovation in Large, Mature Organizations: Overcoming Innovation-to-Organization Problems." *Academy of Management Journal* Vol.39, No.5, p.1120-1153.
- Dougherty 2001**, Dougherty, D., "Re-imagining the Differentiation and Integration of Work for Sustained Product Innovation", *Organization Science*, Vol.12, No.5, 2001, p.612-631.
- Draijer 1997**, Draijer, C., "Optical and Conductive Properties of Rare Earth Hydrides", Master Thesis, Eindhoven University of Technology, 1997.
- Dutton & Dukerich 1991**, Dutton, J.E., Dukerich, J.M., "Keeping an Eye on the Mirror: Image and Identity in Organizational Adaptation", *Academy of Management Journal*, Vol.34, No.3, 1991, p.517-554.
- Dutton 1994**, Dutton, J.E., et al., "Organizational Images and Member Identification, *Administrative Science Quarterly*, Vol.39, 1994, p.239-263.

- Edge 1995**, Edge, G., "Thinking about the Technology Future", R&D Management, Vol.25, No.2, 1995, p.117-129.
- Egidi 1997**, Egidi, M., "Technological and Organizational Innovations as Problem-Solving Activities" In Antonelli, G., De Liso, N., "Economics of Structural and Technological Change", Routledge, London, New York, 1997.
- Eisenhardt 1989a**, Eisenhardt, K.M., "Building theories from case study research", Academy of Management Review, Vol.14, No.4, 1989, p.532-550, AOM.
- Eisenhardt 1989b**, Eisenhardt, K.M., "Agency Theory: An Assessment and Review", Academy of Management Review, Vol.14, No.1, 1989, p.57-74.
- Eisenhardt & Trabizi 1996**, Eisenhardt, K.M., Tabrizi, B.N., "Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry", Administrative Science Quarterly, Vol. 40, 1995, p.84-110.
- Faulkner 1994**, Faulkner, W., "Conceptualization Knowledge Used in Innovation: A second look at the Science-Technology Distinction and Industrial Innovation", Science, Technology & Human Values, Vol.19, No. 4, 1994, p.425-458.
- FETC 1997**, Federal Energy Technology Centre report 1997: The Federal Energy Technology Centre of the US department of Energy spend 186 million dollar on new technologies capable of taking up the task of environmental cleaning of Department of Energy sites. In a five year period 86 technology developments were started, 38 were completed of which 20 were abandoned and 18 entered the test phase of which 12 were implemented. From the remaining 48 ongoing projects 2 were entering deployment. So after 5 years the success rate was: $14/86 = 16.3\%$.
- Feldman & Pentland 2003**, Feldman, M.S., Pentland, B., "Reconceptualization Organizational Routines as a Source of Flexibility and Change", Administrative Science Quarterly, Vol. 48, 2003, p.94-118.
- Felin & Foss 2005**, Felin, T., Foss, N., "Strategic Organization A field in search of micro-foundations", Strategic Organization Vol. 3, No. 4, 2005, p.441-455.
- Foss 2001**, Foss, N.J., "Leadership, Beliefs and Coordination" Industrial and Corporate Change, Vol.10, No.2, 2001, p.357-388.
- Galbraith 1973**, Galbraith, J.R., "Designing Complex Organizations", Addison-Wesley Publishing Company, Reading, MA, 1973.
- Garud & Van De Ven 1992**, Garud, R., Van De Ven, A.H., "An Empirical Evaluation of the Internal Corporate Venturing Process", Strategic Management Journal, Vol. 13, 1992, p.93-109.
- Garud & Rappa 1994**, Garud, R., Rappa, M.A., "A Socio-Cognitive Model of Technology Evolution: The case of Cochlear Implants", Organization Science, Vol. 5, No. 3, 1994.
- Garud & Karnoe 2001**, Garud, R., Karnoe, P., "Path Creation as a Process of Mindful Deviation", In Garud, R. and Karnoe, P., Eds, "Path dependence and creation", p.1-38, Mahwah, NJ & London: Laurence Erlbaum Assoc.
- Gersick 1988**, Gersick, C.J.G., "Time and transition in work teams. Toward a new model of group development", Academy of Management Journal, Vol.31 1988, p.9-41.

References

- Gersick 1991**, Gersick, C.J.G., "Revolutionary Change Theories: a Multilevel Exploration of the Punctuated Equilibrium Paradigm", *The Academy of Management Review*, Vol. 16, No. 1, 1991, p.10-36.
- Glaser & Strauss 1967**, Glaser, B.G., Strauss, A.L., "The Discovery of Grounded Theory", Aldine, Chicago IL, 1967.
- Goldratt & Cox 1986**, Goldratt, E.M., Cox, J., "The Goal, a Process of Ongoing Improvement", Croton-on-Hudson, North River Press, 1986.
- Goldratt 1997**, Goldratt, E.M., "Critical Chain", North River Press, 1997.
- Gort & Klepper 1982**, Gort, M., Klepper, S., "Time paths in Diffusion of Product Innovations", *Economic Journal*, Vol.92, No.367, 1982, p.630-653.
- Grant 1996a**, Grant, R.M., "Towards a knowledge based theory of the firm", *Strategic Management Journal*, Vol.17, 1996, p.109-122.
- Grant 1996b**, Grant, R.M., "Prospering in Dynamically-competitive Environments: Organizational Capability as Knowledge Integration", *Organization Science*, Vol.7, No.4, 1996, p.375-387.
- Gregory 1995**, Gregory, M.J., "Technology management: a process approach", *Proceedings of the Institution of Mechanical Engineers*, Vol. 209, 1995, p. 347-356
- Groot 1961**, Groot, A.D. de, "Methodologie, Grondslagen van Onderzoek en Denken in de Gedragwetenschappen", 's Gravenhage, Mouton, 1961 (Dutch)
- Gummesson 2000**, Gummesson, E., "Qualitative Methods in Management Research", Sage, London, 2000.
- Gulati 1998**, Gulati, R., "Alliances and Networks", *Strategic Management Journal*, Vol.19, 1998, p.293-317.
- Hargadon 2003**, Hargadon, A., "How Breakthroughs Happen: The Surprising Truth About How Companies Innovate", Harvard Business School Press, Boston, MA., 2003.
- Harryson 1995**, Harryson, S., "Japanese R&D Management: A Holistic Network Approach", Thesis St Galen Hochschule, 1995.
- Houser & Clausing 1988**, Houser, J.R., Clausing, D., "The House of Quality", *Harvard Business Review*, May-June 1988, p.63-73.
- Halman 2003**, Halman, J.I.M., et al., "Platform-driven Development of Product-Families", *Journal of Product Innovation Management*, Vol.20, 2003, p.149-162.
- Hardy & Dougherty 1997**, Hardy, C., Dougherty, D., "Powering Product Innovation", *European Management Journal*, Vol.15, No.1, 1997, p.16-27.
- Heracleous & Barrett 2001**, Heracleous, H., Barrett, M., "Organizational Change As Discourse: Communicative Action and Deep Structures in Context of Information Technology Implementation", *Academy of Management Journal*, Vol. 44, No.4, August 2001.
- Hippel 1976**, Hippel, E. von, "The Dominant Role of Users in the Scientific Instrumentation Innovation Process", *Research Policy*, Vol. 5, 1976, p.212-239.
- Hippel 1988**, Hippel, E. von, "Sources of Innovation", Oxford University Press, New York, 1988.

- Howells 1994**, Howells, J., "A Socio-Cognitive Approach to Innovation", *Research Policy*, Vol.24, 1995, p.883-894.
- Huiberts 1995**, Huibers, J.N., "On the road to dirty metallic atomic Hydrogen", PhD thesis, VU University, Amsterdam, 1995.
- Huiberts 1996**, Huibers, J.N., et al."Yttrium and Lanthanum Hydride Films, with Switchable Optical Properties", *Nature*, Vol.380, No.6571 1996.
- Hutchins 1991**, Hutchins, E., "The Social Organization of Distributed Cognition", In Resnick, L.B., Levine, J.M., Teasley, S.D., (Eds), "Perspectives on Socially Shared Cognition", American Psychological Association, Washington D.C., 1991.
- Iansiti 1993**, Iansiti, M., "Real-World R&D: Jumping the Product Generation Gap", *Harvard Business Review*, Vol.71, No.3, 1993, p.138-147.
- Iansiti 1995**, Iansiti, M., "Science-based Product Development: An Empirical Study of the Mainframe Computer Industry", *Production and Operations Management Journal*, Vol.4, No.4, 1995, p.335-359.
- Iansiti & West 1997**, Iansiti, M., West J., "Technology Integration: Turning Great Research into Great Products", *Harvard Business Review*, Vol.75, No.3, 1997, p.69-78.
- Iansiti & West 1999**, Iansiti, M., West, J., "From Physics to Function: An Empirical Study of R&D Performance in the Semiconductor Industry", *Journal of Product Innovation Management*, Vol.16, No.4, 1998, p.385-399.
- Imai 1986**, Imai, I., "Kaizen: The Key to Japan's Competitive Success", Random House Inc. New York, 1986
- Janis 1972**, Janis, I.L., "Victims of groupthink", Houghton Mifflin, Boston, 1972.
- Jelinek 1979**, Jelinek, M., "Institutionalizing Innovation", Praeger, New York, 1979.
- Jelinek & Schoonhoven 1994**, Jelinek, M., Schoonhoven, C. B., "The Innovation Marathon", Jossey-Bass, San Francisco, CA, 1994.
- Jelinek 2003**, Jelinek, M., "Enacting the Future: a Time- and Levels-Based View of Strategic Change", *Research in Multilevel Issues: An Annual Series*, Dansereau, F., Yammarino, F. J., New York, Elsevier. Vol.2, 2003, p.303-349.
- Kim & Wilemon 2002**, Kim, J., Wilemon, D., "Focusing the Fuzzy Front-End in New Product Development", *R&D Management*, Vol.32, No.4, 2002, p.269-279.
- King 1998**, King, N. ,in Symon, G., Cassell, C, (Eds), "Qualitative Methods and Analysis in Organizational Research: a Practical Guide", Sage, London, 1998.
- Klahr & Simon 1999**, Klahr, D. and Simon, H.A., "Studies of Scientific Discovery: Complementary Approaches and Convergent Findings", *Psychological Bulletin*, Vol.125, No.5, 1999, p.524-543.
- Koen 2001**, Koen, P., et al., "Providing Clarity and a Common Language to the Fuzzy Front End", *Research-Technology Management*, p.46-55, March-April, 2001.
- Kogut & Zander 1992**, Kogut, B., Zander, U., "Knowledge of the firm, combinative capabilities and the replication of technology", *Organization Science*, Vol. 3, No. 3, 1992, p. 383-397.

References

- Koopman 1957**, Koopman, T.C., “Three essays in the state of economic science”, McGraw-Hill, New York, 1957.
- Kirton 1976**, Kirton, M.J., “Adaptors and Innovators: A Description and Measure”, *Journal of Applied Psychology*, Vol. 61, 1976, p.622-629.
- Krippendorff**, Krippendorff, <http://pespmc1.vub.ac.be/ASC/Kripp.html>.
- Kreider 1995**, Kreider, G. , et al., “An mK x nK Modular Image Sensor Design”, *IEDM 95*, Washington DC, Dig. Techn. Papers, 1995, p. 155-158.
- Kuhn 1970**, Kuhn,T.S., “The structure of scientific discovery” , Chicago: University of Chicago Press (2nd ed.), 1970.
- Kuhn 1977**, Kuhn,T.S. “The essential tension: selected studies in scientific tradition and change”, University of Chicago Press, Chicago, 1977.
- Larsson 1998**, Larsson, R., et al., “The Interorganizational Learning Dilemma: Collective Knowledge Development in Strategic Alliances”, *Organizational Science*, Vol.9, No.3, 1998, p.285-305.
- Lemmens 2003**, Lemmens, C., “Network Dynamics and Innovation: The effects of Social Embeddedness in Technology Alliance Blocks”, Thesis Eindhoven University of Technology , 2003.
- Levinson 1978**, Levinson, D.J., “The seasons of a man’s life”, Knopf, New York, 1978
- Lipkin 1996**, Lipkin, R., in *Science News*, March 23 1996, Vol. 140, No. 12, p.182.
- Littler 1993**, Litler, D., et al., “Collaboration in New Technology-based Product Markets”, *Technology Analysis & Strategic Management*, Vol.5, No.3, 1993, p.211-233.
- Liyanage & Barnard 2003**, Liyanage, S., Barnard, R., “Valuing of Firms’ Prior Knowledge: A Measure of Knowledge Distance”, *Knowledge and Process Management*, Vol.10, No.2, 2003, p.85-98.
- Miles & Huberman 1994**, Miles, M.B and Huberman, A.M., “Qualitative data Analysis”, Sage, Newbury Park, 1994.
- Malerba & Orsenigo 1996**, Malerba, F., Orsenigo, L., “The Dynamics and Evolution of Industries”, *Industrial and Corporate Change*, Vol.5, No.1, 1996, p.51-87.
- Marsili 2001**, Marsili, O., “Technological Regimes” in “The Anatomy and Evolution of Industries: Technological Change and Industrial Dynamics”, ed. Elgar, E., p.89-107, Cheltenham, 2001.
- McClure 2003**, McClure, B., “Buy into Corporate Research”, Investopedia, Forbes Digital Company, 2003.
- Mintzberg 1976**, Mintzberg, H. (1976), The Structure of “Unstructured” Decision Processes, 21, 246-275.
- Mohr 2005**, Mohr, J., et al., “Marketing of High-Technology Products and Innovations”, 2nd edition, Pearson Prentice Hall, Pearson Education Inc, New Jersey, 2005.

- Moorman & Miner 1997**, Moorman, C., Miner, A.S., “The Impact of Organizational Memory on New Product Performance and Creativity”, *Journal of Marketing Research*, Vol.34, 1997, p.91-106.
- Morgan & Liker 2006**, Morgan, J.M., Liker, J.K., “The Toyota Product Development System: Integrating People, Process and Technology”, Productivity Press, 2006
- Mowery & Rosenberg 1989**, Mowery, D. C. and N. Rosenberg, “Technology and the Pursuit of Economic Growth”, Cambridge University Press, Cambridge, UK, 1989.
- Mowery & Rosenberg 1998**, Mowery, D. C. and N. Rosenberg, “Paths of Innovation: Technological Change in 20th-Century America”, Cambridge University Press, Cambridge, UK, 1998.
- Munir & Jones 2004**, Munir, K.A., Jones, M., “Discontinuity and After: The Social Dynamics of Technological Evolution and Dominance”, *Organization Studies*, Vol.25, No.4, 2004, p.561-581.
- Nelson & Winter 1982**, Nelson, R.R., Winter, S.G., *An evolutionary theory of economic change*, Cambridge, Harvard Press, 1982.
- Nevens 1990**, Nevens, T. M., et al., “Commercializing Technology: What the Best Companies Do”, *Harvard Business Review*, Vol.68, No.3, 1990, p.154-163.
- Newell & Simon 1972**, Newell, A. and Simon, H.A. “Human Problem Solving”, Prentice Hall, Englewood Cliffs, 1972.
- Nicholson 1998**, Nicholson, G.C., “Keeping Innovation Alive”, *Research Technology Management*, Vol. , 1998, p.34-40
- Nonaka 1991**, Nonaka, I., “The Knowledge Creating Company”, *Harvard Business Review*, November-December 1991.
- Nonaka 1994**, Nonaka, I., “A Dynamic Theory of Organizational Knowledge Creation”, *Organizational Science*, 5(1), 1994, p.14-37.
- Nonaka & Takeuchi 1995**, Nonaka, I., Takeuchi, H., “The Knowledge Creating Company: How Japanese Companies Create the Dynamics of Innovation”, Oxford University Press, Oxford, UK, 1995
- Nonaka 2006**, Nonaka, I., et al., “Organizational Knowledge Creation Theory: Evolutionary Paths and Future Advances”, *Organizational Studies*, Vol. 27, No.8, 2006, p.1179-1208.
- Nonaka 2009**, Nonaka, I., von Krogh, G., “Tacit Knowledge and Knowledge Conversion: Controversy and Advancement in Organizational Knowledge Creation Theory”, *Organization Science*, Vol.20, No.3, 2009, p.635-652.
- Nooteboom 1993**, Nooteboom, B., “Schumpeterian and Austrian entrepreneurship: A unified process of innovation and diffusion”, Research Report RR 1993-01. Faculty of Management and Organization, Groningen, 1993
- Nooteboom 1997**, Nooteboom, B., “Path dependence of Knowledge: Implications for the Theory of the Firm”, In Magnusson, L., Ottosson, J., (eds), “Evolutionary economics and path dependence”, p.57-78, Edward Elgar, Cheltenham, UK.

References

- Nooteboom 2000**, Nooteboom, B., et al., "Learning and Innovation in Organizations and Economies", Oxford University Press, Oxford, 2007
- Nooteboom 2007**, Nooteboom, B., et al., "Optimal Cognitive Distance and Absorptive Capacity", *Research Policy*, Vol.36, 2007, p.1016-1034.
- Orlikowski 1992**, Orlikowski, W., 'The duality of technology: Rethinking the concept of technology in organizations', *Organization Science*, Vol.3, No.3, 1992, p.398-427.
- Orlikowski 2002**, Orlikowski, W., "Knowing in practice: Enacting a Collective Capability in Distributed Organizing", *Organizational Science*, Vol.13, No.3, 2002, p.249-273.
- Ouwerkerk 1998**, Ouwerkerk, M., "Electrochemically induced optical switching of $\text{Sm}_{0.3}\text{Mg}_{0.7}\text{H}_x$ thin layers", *Solid State Ionic*, Vol. 113, No.15, 1998, p. 431-437.
- Pettigrew 1985**, Pettigrew, A. M., "The Awakening Giant: Continuity and Change in ICP", Basil Blackwell, Oxford, UK, and New York, 1985.
- Pettigrew & Fenton 2000**, Pettigrew, A.M., Fenton, E.M., "Complexities and Dualities in Innovative Forms of Organizing", in Pettigrew, A.M., Fenton, E.M., (Eds) "The Innovating Organization", Sage Publications, London, 2000.
- Pettigrew 2001**, Pettigrew, A.M., et al., "Studying Organizational Change and Development: Challenges for Future Research", *Academy of Management Journal*, Vol. 44, No. 4, Augustus 2001.
- Petroski 1996**, Petroski, H., "Invention by Design: How Engineers get from Thought to Thing", Harvard University Press, Cambridge, MA., 1996.
- Pinch & Bijker 1987**, Pinch, T.J., Bijker, W.E., "The Social Construction of Facts and Artifacts", in: "The Social Construct of Technological Systems", MIT Press, Cambridge, 1987.
- Phaal 2001**, Phaal, R., et al., "Technology management process assessment: a case study", *International Journal of Operations & Production Management*, Vol 21, No. 8, 2001, p. 1116-1132.
- Polanyi 1950**, Polanyi, M., "Scientific Beliefs", *Ethics*, Vol. 61, No.1, 1950, p.27-37.
- Polanyi 1962**, Polanyi, M., "Republic of Science: Its political and economical theory", *Minerva*, Vol.1, 1962, p.54-74.
- Polanyi 1966**, Polanyi, M., "The Tacit Dimension", Routledge, London, 1966
- Porter 1983**, Porter, M.E., "The Technological Dimension of Competitive Strategy", in Rosenbloom, R.S. (ed.), "Research on Technological Innovation, Management and Policy", vol.1, p.1-33. JAI Press, Greenwich, 1983.
- Popper 1972**, Popper, K.R., "The Logic of Scientific Discovery", Hutchinson, London, 1972.
- Ren 2006**, Ren, Y., et al., "The Contingent Effects of Trans-active Memory: When Is It More Beneficial to Know What Others Know?", *Management Science*, Vol.52, No.5, p. 671-682, May 2006.
- Rogers 1983**, Rogers, E., "Diffusion of Innovations", New York, Free Press, 1983.

- Rosenberg 1992**, Rosenberg, N., R. Landau, et al., Eds. "Technology and the Wealth of Nations", Stanford University Press, Stanford, CA, 1992.
- Rosenkopf & Nerkar 2001**, Rosenkopf, L., Nerkar, A., "Beyond Local Search: Boundry-Spanning, Exploration, and Impact in the Optical Disk Industry", Strategic Management Journal, Vol.22, No.4, p. 287-306, 2001, John Wiley & Sons, Ltd.
- Roy 1952**, Roy, D., "Quota Restriction and Goldbricking in a Machine Shop", The American Journal of Sociology, Vol.57, No.5, 1952, p.427-442.
- Roy 1954**, Roy, D., "Efficiency and "The Fix": Informal Intergroup Relations in a Piecework Machine Shop", The American Journal of Sociology, Vol.60, No.3, 1954, p.255-266.
- Saffold 1988**, "Culture traits, strength and organizational performance", Academy of Management Review, Vol.13, 1988, p.546-558
- Salvato 2009**, Salvato, C., "Capabilities Unveiled: The role of ordinary Activities in the Evolution of Product Development Process", Organizational Science, Vol. 20, No.2, 2009, p.384-409, 2009
- Santos & Eisenhardt 2005**, Santos, F.M., Eisenhardt, K.M., "Organizational Boundaries and Theories of Organization", Organizational Science, Vol. 16, No. 5, 2005, p. 491-508,
- Sarasvathy 2001**, Sarasvathy, S. D., "Causation and Effectuation: Toward a theoretical shift from economic inevitability to entrepreneurial contingency.", Academy of Management Review 26(2): 243-263 2001.
- Schilling 2008**, Schilling, M.A., "Strategic Management of Technological Innovation", McGraw-Hill, New York, 2008.
- Schumpeter 1932**, Schumpeter, J.A., "The theory of Economic Development", Harvard Business Press. Cambridge, MA, 1932.
- Shanklin and Ryans 1987**, Shanklin, W., Ryans, J., "Essentials of Marketing High Tech Technology", Lexington, MA, 1987.
- Sheremata 2000**, Sheremata, W.A., "Centrifugal and Centripetal Forces in Radical New Product Development Under Time Pressure", Academy of Management Review, Vol.25, No.2, 2000, p.389-408.
- Simon 1965**, Simon, H.A., "Administrative Behavior: A Study of Decision-Making Processes in Administrative Organizations", 2th ed., The Free Press, 1965.
- Simon 1986**, Simon, H.A., et al., "Research Briefings: Report of the Research Briefing Panel on Decision Making and Problem Solving", National Academy of Sciences. National Academy Press, Washington, DC, 1986.
- Sitkin & Pablo 1992**, Sitkin, S.B., Pablo, A.L., "Re-conceptualizing the Determinants of Risk Behaviour", Academy of Management Review, Vol.17, No.1, 1992, p.9-38.
- Sluis 1997**, Sluis, van der, P., et al. "Optical Switches Based on Magnesium Lanthanide Alloy Hydrides", Appl. Phys. Letters, Vol. 70, No.25, 1997, p.3356-3358.

References

Sluis 1999, Sluis, van der, P., “Chemochromic Optical Switches Based on Metal Hydrides”, *Electrochim. Acta*, Vol.44, 1999, p.3063-3066.

Smircich 1983, Smircich, L., “Organization as shared meaning”, In Pondy, L.R., Frost, P.J., Morgan, G., Danridge, T.C., (Eds.) *Organizational Symolism*, JAI Press, Greenwich, CT, p.55-65, 1983.

Smit 2001, Smit, Eric, “Interview met Roel Pieper”, Quote, 24 January 2001, in Dutch:

Eric Smit: Nee, ik zeg alleen dat deze technologie van Sloot nog steeds een fenomenale potentie heeft en dat je eerder de omvang van de waarde van deze technologie hebt proberen te bagatelliseren.

Roel Pieper: Je bent twee dingen totaal vergeten. Echt, totaal vergeten. Ten eerste weet jij niet hoe moeilijk het is om technologie op de markt te brengen. Dat weet jij gewoon niet. Dat weet ik wel en dat weet jij niet. Het tweede punt is dat de technologie van Sloot nog niet gereed was. Dat heb ik je gezegd. Het is een piramide op zijn punt. Het onderste deel moet wel verdomd goed zijn, wil het de rest kunnen dragen. Het feit was dat het nog niet af was. Dan kan je zeggen dat het ontbrekende deel nu twintig procent van tien miljard is, of misschien is het de hele twintig miljard. Snap je? Dat ben je helemaal vergeten.

Sorensen 2002, Sorensen, J.B. “The Strength of Corporate Culture and the Reliability of Firm Performance”, *Administrative Science Quarterly*, Vol.47, 2002, p.70-91.

Spencer 2003, Spencer, J.W., “Firm’s Knowledge-Sharing Strategies in the Global Innovation System”, *Strategic Management Journal*, Vol. 24, 2003, p.217-233.

Sydow 2009, Sydow, J., et al., “Organizational Path Dependence: Opening the Black Box, *Academy of Management Review*, Vol. 34, No.4, 2009, p.689-709.

Symon & Cassell 1998, Symon, G., Cassell, C, (Eds), “Qualitative Methods and Analysis in Organizational Research: a Practical Guide”, Sage, London, 1998.

Symon 2005, Symon, G., “Exploring Resistance from a Rhetorical Perspective”, *Organization Studies*, Vol.26, No.11, 2005, 1641-1663.

Teece 1986, Teece, D.J., “Profiting from Technological Innovation”, *Research Policy*, Vol.15, No.6, 1986, p.285-306.

Teece 1996, Teece, D.J., “Firm Organization, Industrial Structure, and Technological Innovation”, *Journal of Economic Behavior & Organization*, Vol.31, 1996, p.193-224.

Teubal 1996, Teubal, M., “On User Needs and Need Determination”, In Teubal, M., et al. (Eds) “Industrial Innovation”, Kluwer Dordrecht, 1996.

Tsoukas 2005, Tsoukas, H., “A Dialogical Approach to the Creation of New Knowledge in Organizations”, *Organization Science*, Vol.20, No.6, 2005, p.941-957.

Tushman & Nadler 1978, Tushman, M.L., Nadler, D.A., “Information Processing as an Integration Concept in Organizational Design”, *Academy of Management Review*, Vol. 3, 1978, p.613-624.

- Tushman 1978**, Tushman, M.L., "Technical Communication in R&D Laboratories; The Impact of Project Work Characteristics", *Academy of Management Journal*, Vol.21, No.4, 1978, p.624-645.
- Tushman & Moore 1982**, Tushman, M.L., Moore, W.L., "Readings in the Management of Innovation", Pitman Publishing, Marshfield, MA, 1982.
- Tushman & Romanelli 1985**, Tushman, M. and Romanelli, E. "Organizational evolution: A Metamorphosis Model of Convergence and Ceorientation", In Cummings, L.L. and Staw, B.M. (eds.), "Research in Organizational Behavior", Vol.7, p.171-222, JAI Press, Greenwich, 1985.
- Tushman & O'Reilly 1996**, Tushman, M., O'Reilly, C.A., "Ambidextrous Organizations: Managing Evolutionary and Revolutionary Change", *California Management Review*, Vol.38, No.4, 1996, p.8-30.
- Van Aken & Weggeman 2000**, van Aken, J.E., Weggeman, M.C.D.P., "Managing Learning in Informal Innovation Networks: Overcoming the Daphne Dilemma", *R&D Management*, Vol.30, No.2, 2000, p.139-149
- Van Aken 2005**, van Aken, J.E., "Management Research as a Design Science: articulating the research products of mode 2 knowledge production". *British Journal of Management*, Vol.16, 2005, p.19-36.
- Van Aken & Nagel 2004**, van Aken, J.E., Nagel, A.P., "Organizing and Managing the Fuzzy Front End of New Product Development", Eindhoven University of Technology, Ecis working paper 04.12, 2004.
- Van De Ven 1999**, Ven, A.H. Van de, Polley, D.E., Garud, R.. "The Innovation Journey", Oxford University Press, Oxford, 1999.
- Van De Ven & Poole 1995**, Van De Ven, A.H., Poole, M.S., "Explaining Development and Change in Organization", *Academy of Management Review*, Vol. 20, No. 3, 1995, p.510-540.
- Vos 2002**, Vos, J.P., "The Making of Strategic Realities", Thesis Eindhoven University of Technology, Eindhoven University Press, Eindhoven, The Netherlands, 2002.
- Weggeman 1995**, Weggeman, M.C.D.P., "Collectieve Ambitie Ontwikkeling", Thesis Tilburg University, (Dutch), 1995.
- Weggeman 1997**, Weggeman, M.C.D.P., "Kennismanagement: inrichting en besturing van kennisintensieve organisaties", (Dutch) Schiedam, Scriptum, 1997.
- Weggeman 2000**, Weggeman, M.C.D.P., "Kennismanagement: de praktijk", (Dutch) Schiedam, Scriptum, 2000.
- Weick 1993**, Weick, K.E., Roberts, K.H., "Collective Mind in Organizations: Heedful Interrelating on Flight Decks", *Administrative Science Quarterly*, 38, 1993, p. 357-381.
- Weick 1995**, Weick, K.E., "Sense making in Organizations", Sage, Thousand Oaks, CA, 1995.
- Winter 1984**, Winter, S.G., "Schumpeterian Competition in Alternative Technological Regimes", *Journal of Economic Behaviour and Organization*, Vol. 5, 1984, p.287-320.

References

- Winter 1987**, Winter, S.G., “Knowledge and Competence as Strategic Assets” in Teece, D.J. (ed), “The competitive Challenge”, p.159-184, Ballinger Publishing Company, Cambridge M.A., 1989.
- Winter 2003**, Winter, S.G., “Understanding Dynamic Capabilities”, Strategic Management Journal, Vol.24, No.10, 2003, p.991-995.
- Wheelwright and Clark 1992**, Wheelwright, S.C., Clark, K.B., “Revolutionizing Product Development”, New York, Free Press, 1992.
- Wooten 1972**, Wooten, F., “Optical Properties of Solids”, Academic Press, 1972
- Yin 1994**, Yin, R.K., “Case Study Research: Design and Methods”, Sage, Newbury Park., 1994.
- Zammuto 2007**, Zammuto, R.F., et al., “Information Technology and the Changing Fabric of Organization”, Organization Science, Vol.18, No.5, 2007, p.749-762.
- Zhang 2008**, X.P. Zhang, T. Sim, X.P. Miao, “Enhancing Photographs with Near Infrared Images”, IEEE Computer Society Conference on Computer Vision and Pattern Recognition 2008, Anchorage, US.
- Zollo & Winter 2002**, Zollo, M., Winter, S.G., “Deliberate learning and the evolution of dynamic capabilities”, Organization Science, Vol.13, No. 3, 2002, p. 339-351.
- Zyphur 2009**, Zupher, M.J., “When mindsets collide: Switching analytical mindsets to advance organization science”, Academy of Management Review, Vol.34, No.4, 2009, p.677-688.

Collective Frame of Reference in Technology Developments

Appendix A: Management Methods

1 The level of definition and broadness of recognition of technological needs of the market. Management method: Technology adoption framework

Rogers [Rogers 1983] developed a framework that describes the process that users follow for adoption of new technology intensive products. Based on this framework, an organization is able to evaluate the chance of market acceptance.

User decision factor	Description
1. Relative advantage	The benefits of adopting the new technology compared to the costs; The so-called cost-of-ownership is very relevant for the user. An organization should be able to understand the overall user business case so that can be understood what is the up- and or down side of the new technology.
2. Compatibility	The extent to which adopting and using the new technology is based on existing ways of operation and fit with the industrial regime. In many ways the CFR of the user needs to be taken into account. A new technology that fits with an evolving CFR at the users side has much more chance of a smooth adoption, while a technology that requires a radical change of the CFR of the user is much more difficult. A user that is required to change its organization in order to adopt a new technology will need time and most likely a strong internal motivation than an external push
3. Complexity	The complexity of the new technology is a factor that users will take into account as it introduces risk. Like understanding the business case of the user, an organization should understand the risk analysis and mitigations measures of the user.
4. Evaluation	A user will run trials before adopting a new technology. Some technologies can be easily evaluated, e.g., by providing the user with an evaluation setup. For process technologies this is much more difficult. A really radically different process compared to the industry's installed base may require a trial process installation. Potential users can evaluate the prototype products running from this trial installation.
Communication of benefits	Especially for new and unknown technologies, the characteristics need to be communicated to create user awareness. This awareness allows the potential user to see benefits that a new technology may bring to its operations. If the organization sees a clear benefit for a user group than these benefits can be addressed in specific communications aimed at this user group.
Observable benefits	The benefits of a new technology can be very observable by the user and non-users, which helps to adopt the new technology. In case these benefits are less observable non-users will be less interested to adopt the technology as it allows them to stick to the existing paradigm without losing competitiveness.

Table A1.1: User decision factors related to a new technology according to Rogers [Rogers 1983]

A well defined and broadly recognized demand for the technology helps the organization to plan the development of the technology. The needs in the market are

susceptible to change over time and this requires a periodic verification of the needs and change of needs in the market during the often long lasting technology development process.

2. The level of maturity of the technology.

Management Method: Technology Readiness Levels

The maturity of the technology can be measured in several ways, and assuming that modern technology originates from science, technology starts with scientific principles, and if the technology is relevant, it will be incorporated in a product and proven to be qualified for a particular application. So a maturity scale for technology should form a spectrum ranging from the origin of technology; scientific principles, to the successful application: a product. The United States Government uses a systematic description for the maturity of the technology which is indicated by the Technology Readiness Level (TRL) running from 1 to 9 (see Table A1.2). Indeed the scale (TRL=1) starts with the reporting and observing of the scientific principles from which a technology will originate. On the other end of the scale (TRL=9), the technology has been proven to be successful in an application. Although this method is mainly used for complex defense and security systems and space systems, it is considered to be relevant for evaluating the technology in general. The table below shows the TRL levels which are considered to be relevant for an organization about to invest in a new technology development.

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high

Appendix A

environment	fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual (system) prototype in an operational environment, such as in an vehicle or under medical conditions. Examples include testing the prototype in a medical X-ray environment.
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true (system) development. Examples include developmental test and evaluation of the (sub) system in its higher level system to determine if it meets design specifications.
9. Actual system proven through successful operations	Actual application of the technology in its final form and under user conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true (system) development. Examples include using the system under operational user conditions.

Table A1.2: The Technology Readiness Levels (TRL) adapted from the technology maturity classification defined by the United States Government for technologies that are applied in critical systems. Taken from the Defense Acquisition Guidebook [DOD 2006]

3. The determination of long term trends and the impact for/from the new technology;

Management Method: Technology DESTEP Analysis, Technology SWOT and Market requirement/technology performance correlation

Demographic Economical Social Technological Ecological Political (DESTEP)

The DESTEP trend analysis is a tool that is applied to identify technological trends in society. Although this method is not market specific, it provides a trend of needs in the society. Based on brainstorming sessions the trends in six areas of society are evaluated against certain requirements. Based on these requirements the impact, both positive and negative, of a certain technology is evaluated. However, prior to the gap analysis, the organization has to determine which technologies are considered for further development. This method is not very exact, as it highly based on deduction or sometimes on informed speculation.

Market Requirement/Technology Potential Correlation matrix

In order to determine the requirements that the new technology has to fulfill, the organization has to have sufficient understanding about what the market may require. The requirements for new markets can be hard to acquire mainly because the users are not familiar with the benefits/restrictions of the new technology. Also latent requirements can play a role: Users have latent needs that are not translated into specific requirements. Despite all these barriers it is rewarding to obtain this insight

into the market needs as it can serve as a discriminating factor for technology benchmarking. This benchmarking can be done in a requirement/technology correlation matrix, which is very similar to the QFD method, which is applied for product developments [Houser & Clausing 1988, Akao 1990].

Technology SWOT

One criteria of selecting a technology is to determine what the strengths and weaknesses are from the current technology that is applied. This will teach the organization in which areas their technological position should be strengthened, preferably with maintaining the current strengths.

Although the Strength Weakness Opportunities Treads (SWOT) analysis is done for the position of the organization in relation to the market and market segments that are served, this tool can also be used to evaluate the technology of the organization specifically in relation to the markets that are served. In this perspective the competing technologies that are present in the market space are evaluated with respect to their strengths, weaknesses, opportunities and threads.

The Technology SWOT matrix will provide a qualitative overview of the performance and potential of the technology in specific markets.

In a later stage the identified requirements of the specific markets are matched with various technological options.

4. The magnitude of the gap between the current and required technological and organizational capabilities.

Management Method: Technology Gap Analysis

The technology gap analysis is a method that helps the organization to evaluate what the missing pieces are with respect to the required technology and capabilities. Part of this gap analysis is to understand what the cost of ownership is of a certain technology or capability. Depending on the available capabilities and knowledge this can be significant if this paradigm shift implies that the organization has to be redefined throughout its current constitution. With reason it can be assumed that an organization will decide on a paradigm shift which provides some meaning to the existing elements of organization and that it is unlikely that an organization out of free will decides to destruct itself. This assures that some technologies and capabilities, or more general, knowledge is relevant after the paradigm shift. Therefore some technologies and/or capabilities will link the current paradigm to the new paradigm, which assures a certain efficiency and reduction of cost of the paradigm shift. This is similar to the concept of cognitive distance as discussed by for example Nootboom et al. [Nootboom 2007].

Appendix A

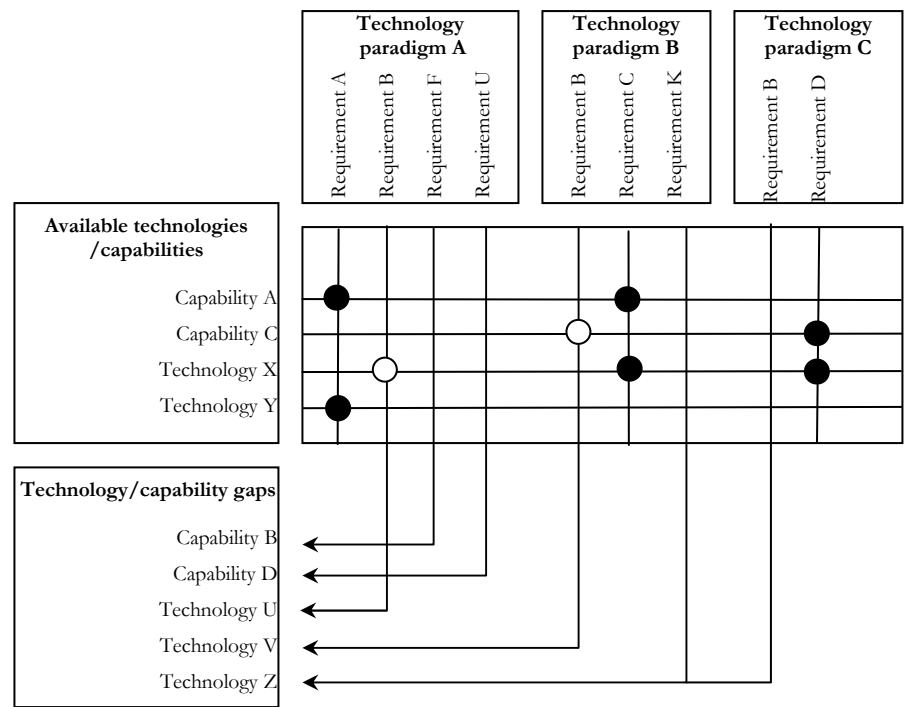


Figure A1.1 : Schematic representation of a Technology gap correlation matrix for several technology paradigms. These technology paradigms impose requirements on to the organization. Based on the current available technologies and capabilities, the organization can determine the technology gap. Although somewhat subjective it represents the required effort and risks associated with the paradigm shift.

5. The financial bandwidth for the development of the new technology.
Management method: Hurdle rate or Net Present Value

The hurdle rate method relies on balancing the investments, the duration of the developments and benefits of a technology development. The so-called hurdle rate is the percentile that determines the present value of the losses and the gains over the course of the development and the years that the technology is implemented and generates revenue in the form of a product or function of a product. The hurdle rate weights the future incomes from a technology less, while the required investments are weighted more. This represents the high risk of technology development; the investments on the shorter terms are certain, while the income on longer term is uncertain (see table A1.3). The magnitude of the hurdle rate is determined by the risk; a lower risk development is represented by a lower hurdle rate, while a higher risk development is represented with a higher hurdle rate. The main criteria for taking on a technology development are to obtain a positive cumulative Net Present Value.

Hurdle rate	30%										
Time line [year]	1	2	3	4	5	6	7	8	9	10	Totals
Revenue [k\$]	\$0	\$0	\$0	\$0	\$0	\$200	\$800	\$1,500	\$4,000	\$5,000	\$11,500
R&D investments [k\$]	\$50	\$100	\$150	\$200	\$200	\$50	\$0	\$0	\$0	\$0	\$750
Earnings Before Income Tax (EBIT) [k\$]	-\$50	-\$100	-\$150	-\$200	-\$200	\$150	\$800	\$1,500	\$4,000	\$5,000	\$10,750
Net Income After Taxes (NIAT) [k\$]	-\$34	-\$68	-\$102	-\$136	-\$136	\$102	\$544	\$1,020	\$2,720	\$3,400	\$7,310
Cash flow [k\$]	-\$34	-\$68	-\$102	-\$136	-\$136	\$102	\$544	\$1,020	\$2,720	\$3,400	\$7,310
Quarterly Hurdle rate	1.00	1.30	1.69	2.20	2.86	3.71	4.83	6.27	8.16	10.60	
Net Present Value [k\$]	\$9	-\$88	-\$172	-\$299	-\$388	\$28	\$113	\$163	\$333	\$321	
Cumulative Cash flow [k\$]	-\$34	-\$102	-\$204	-\$340	-\$476	-\$374	\$170	\$1,190	\$3,910	\$7,310	
Negative Contributing Time [years]	5										
Pay Back Time [years]	6										
Return On Investment	9.75										

Table A1.3: Example of the Net Present Value (NPV) calculation of a technology investment. Typical is the long term before a technology (applied in a product) is gaining revenue and its effect on the NPV. The hurdle rate of 30% represents a high risk investment: Large gains with a relative low investment are expected if the technology succeeds, which is reflected in the ROI of about 10.

Appendix A

The return on investment shows the potential of a successful technology investment; the investments are relatively low compared to the gains. The risk however is significant and this can undo the high return on investment; an average success rate of 15% will provided a weighted Return On Investment of 1.46, which basically shows that a return on investment of 10 is marginal to offset the high risks related to technology development.

6. The availability of technology partners.

Management method: Correlating partners to technology and capability gaps.

Once the organization has identified the technology and capability gaps, technology partners can be identified that can help the organization to bridge the technology gaps. Based on the technology and the capability deficiencies, the partner that provides the best coverage is a priori favorable, although the mutual benefits of the partnering organizations should sufficient to make this technology partnership work.

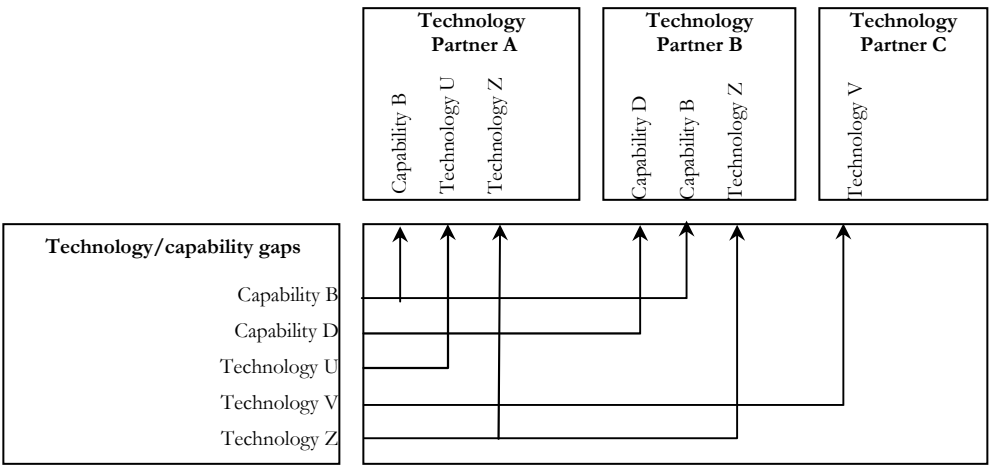


Figure A1.2 : Schematic representation of a Technology gap/partner correlation matrix. Often it requires quite some study to find proper candidates and to obtain enough detail to fill in this correlation matrix. These details are required to evaluate the potential of the technology in relation to the defined gaps.

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Appendix B: Member Checks

Some member checks have been done in order to verify to what extent chapter 3 provides a generic description.

- Do you recognize the phases that are described?
- Do you have the impression that the chapter describes the challenges of technology development properly and sufficiently?
- Are there elements that are missing in the description?
- Based on your experiences is the description general enough or do you have indications that in other industries the technology development is fundamentally different?
- Do you have further recommendations?

Respondent 1

Profile

Respondent 1 has 30+ years experience in the multi-national, high-tech sector, transitioning from an initial electrical and software engineering background through all facets of the business process.

He served with globally recognized corporations including of Litton (Northrop Grumman), Honeywell, British Aerospace, Smiths Industries, in various managerial roles.

From there he transitioned to hands-on executive management of small technology-based enterprises, including of three Toronto Stock Exchange-listed entities, in Chief Executive, or Operating Officer functions.

He has extensive experience in the fields of Mergers/Acquisitions, Private-to-Public Company transitions, together with associated financing and has authored multiple successful proposals pertaining to Federal and Internationally sponsored programs, at the multi-million dollar level (e.g., Defense Industry Participation, Technology Partnerships Canada, Defense Development/Production Sharing Arrangement, SR&ED,...)

Active and effective contributor to independent and academic bodies important in the development of the industry, inclusive of the following roles:

- Director, Canadian Association of Defence & Security Industries
- Past Director, Ontario Aerospace Council
- Past Director, Aerospace Industries Association of Canada
- Member, Canadian Dept for Foreign Affairs Committee for Export Development (SME)
- Board Member, Canadian Institute for Photonic Innovations

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- Past Chair, Advisory Board, Information and Telecommunications Technology, National Research Council
- Founding Chairman, Solid State Opto-Electronics Corporation of Canada

He is founder and co-owner of an independent consultancy that is essentially a “club” of experienced professionals who specialize in providing solutions to high-tech companies who find their internal resources challenged during periods of transition or growth.

Response

Do you recognize the phases which are described in Chapter 3?

Yes, I do recognize the phases you have described and believe you have captured them accurately and completely. I would add that in my experience, many companies do not recognize what phase they are in, and thus misapply management tools to the process, at their cost. (Most commonly, they go into a product development mode, when they are still in truth, at the technology level)

Does the chapter accurately describe and represent the challenges and reasons behind technology deployment?

I think the challenges involved are well described and complete. Maybe some practical examples could help.

Are there missing elements in the chapter?

Over and above my diatribe above, maybe some discussion of the role of rapid prototyping/concept demonstrators may be useful. This tool offers a fast and inexpensive way to sort the wheat from the chaff at the front end of the funnel (or GTO/STO phase). Once again, I think this method is used mostly by the “game-changers”, as, on the face of it, spending money on prototyping when the idea is still in the early birth stage would appear a big waste of money, as there is no prospect of follow-on product revenues from the outcome. However, it is a technique that very rapidly flushes out the pluses and minuses of the underlying technology, and provides researchers valuable practical references to confirm and guide theoretical predictions.

Appendix B

This is in stark contrast the endless business and technical analyses that conventional management approaches teach.

Do you have an indication of industries where technology development is fundamentally different?

Chapter 3 certainly pertains to industries that I am familiar with. I suspect that if you look at heavy industries (civil works, chemicals, etc) you will find that there is no technology development process, which is why they are still stuck in the last century.

While the mechanisms you outline I believe are universal, the examples you present are strongly slanted toward outcomes that result in the development and production of products. I think the rules outlined pertain equally to the technology development of products. Developed economies are becoming increasingly dependent upon the delivering of processes (i.e., services) rather than products for their economic viability. Maybe that's a point worth making.

Respondent 2

Profile

- 1972 Graduate of Dundee College of Technology, Dundee, Scotland. BSc Hons 1st, Mechanical Engineering.
- 1973 thro 2010 (current), employed by DALSA, Waterloo Canada, NCR Corp Waterloo Canada, Burroughs Machines Corp (Unisys), Livingston Scotland, Garrard Engineering (Plessey), Swindon England.
- The first 23 years of my career, was with major corporations, two US based and one British, of Burroughs Unisys), NCR and Garrard (Plessey), in a series of development and management roles, covering Advanced Development, Product Development and Senior Engineering Management, eg Director of Engineering NCR Corp, Waterloo, Canada. All of the above companies had a strong reliance upon Advanced Product & Technology groups, to prime and enable new Product Developments.
- The last 15 have been with DALSA Corp, Waterloo Canada, in a series of management functions, with the current role being that of VP Engineering Operations, DALSA Digital Imaging, Waterloo Canada. DALSA is a small-medium sized Canadian company who invest heavily within Technology and Product Development, through a balance of internal and external, customer funding.

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Response

Do you recognize the phases which are described in Chapter 3?

The phases described of STO, ITO and DTO are ones which I have experienced from my activities with Burroughs Mcs (Unisys), NCR and Garrard Eng (Plessey), as ALL three of these units were part of large corporations, having a well established and formal structures in place, which relied heavily upon the function of Advanced Technology and Advanced Product Development to feed and enable the Product Developments. The output of this Advanced function serviced as elements required for either product differentiation or minimization of technical or schedule risks, during the DTO phase, in Product Developments.

During my activities with NCR, Waterloo, I also witnessed, within the Advanced Technology group, the evolutions of technologies, to address growing market requirements and the maintenance of a competitive edge to the competition, eg shift from the functions of magnetic and optical character recognition to image capture and character recognition, printed and cursive script.

Does the chapter accurately describe and represent the challenges and reasons behind technology deployment?

The chapter provides a good and reasonable position on the reasoning behind and challenges faced in technology development for companies ranging from large to small.

From my history technological options have been used primarily as 'product performance differentiators', either to competitive products or the next generation of product, to provide clear benefits and a solution to end user needs. Although I have witnessed a situation, with Garrard Engineering, where advanced technologies and development prototypes were used as a source of revenue, ie where Garrard had decided not to proceed with a developed technology module, they have actually sold or licensed the IP to a competitor.

The major companies, defined above, all had product structures which could be broken into modules and the approach described in this Chapter, definitely aligns to a product development which can be viewed as a series of interacting module developments.

I have been involved in the Advanced Development of multiple 'technology modules', in the determination of the readiness of a technology to progress to the next level, in the development of prototypes which can be evaluated by prospective end users, in a partnership mode, to validate the proposed benefits and obtain

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feedback before moving toward the formal deployment of a technology within a product development. The 'technology module' approach also enables a quantitative assessment of the technical risks associated with a Product Development, resulting in potentially lower risk architecture. The chapter also makes a salient comments with respect to the challenges faced if a 'technology component/module' requires replacement, as the architecture defined with the initial technology has established a series of interface requirements with other technology modules which now need major update.

The need for a balanced approach to the funding of advanced technologies and/or developments versus product developments is certainly a difficult challenge, especially when faced with short-term budget constraints. This is an issue I have witnessed in all three of the above mentioned large corporations, where the tendency is either to reduce the actual expense or call for a higher level of throughput or winning technologies from the Advanced Development function. Budget measures will occur, in certain years, and therefore a company needs to recognize how they will react to a constraining set of circumstances in their longer-term strategy.

Are there missing elements in the chapter?

From my history I believe you have represented both large and small institutions fairly well in this chapter.

However one item which may warrant your consideration is the establishment and growth of technologies through external funded development projects, ie essentially applying the 'final risk' of the development to the end customer. Thus, even a failure to completely fulfill all of the needs of an externally funded development, could realize successful technology building blocks that would benefit internally funded projects.

Another aspect for your consideration would be the utilization of deployment of new technology within a product development as a source of motivation and excitement for resources to be employed within the project. Now I have witnessed this 'end result' in a few projects which I have had the opportunity to lead. However the deployment of new technology on a project, to create excitement through innovation, may be a strategy to re-engage a Product Development group which is seen to be lacking in motivation.

Do you have an indication of industries where technology development is fundamentally different?

The only difference that I can point to may be the one identified in section 4.0.

Collective Frame of Reference in Technology Developments

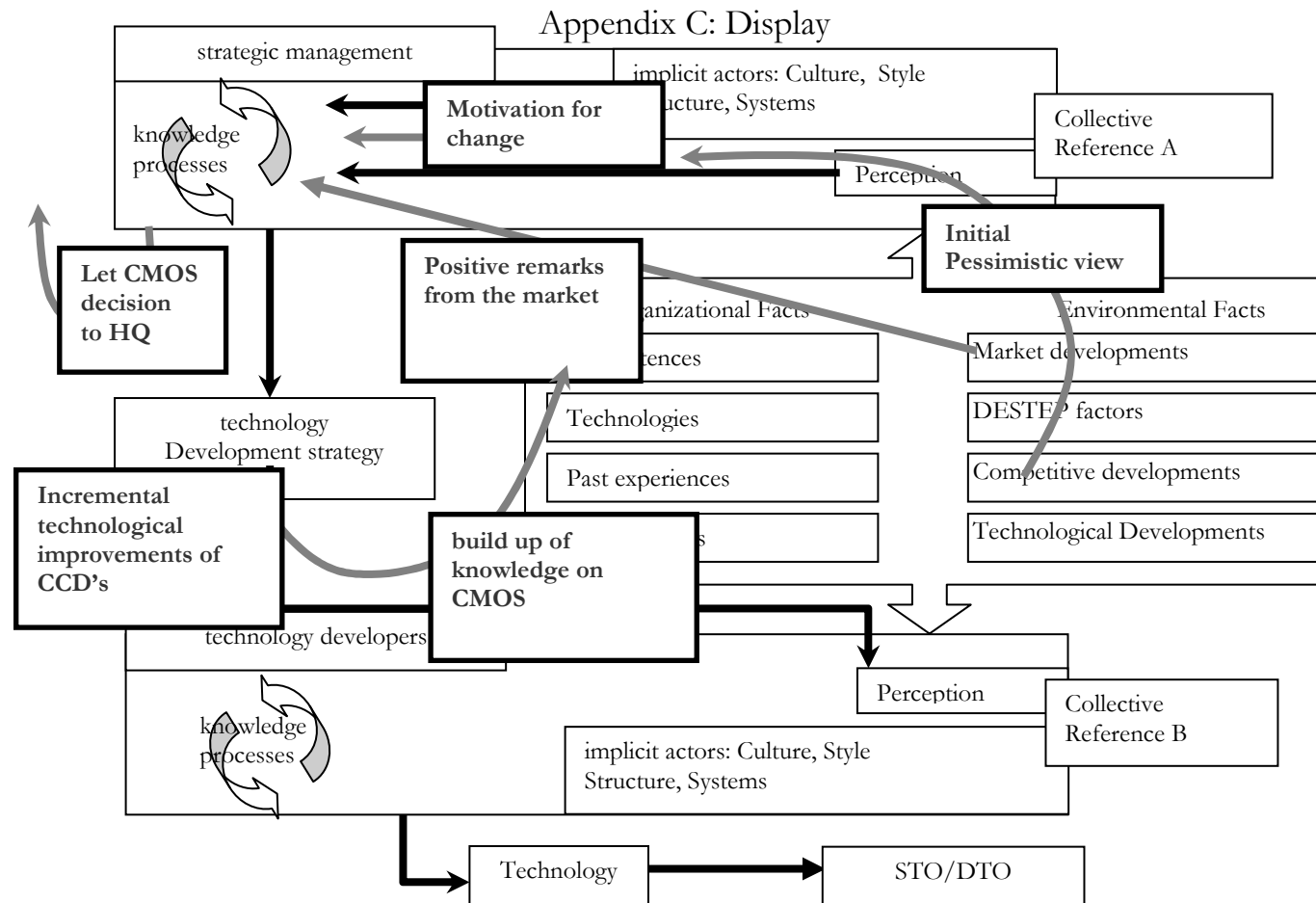


Figure A3.1: An example of a display with the events plotted in a framework describing the case study setting.

Summary

A. Introduction

A wide body of literature describes the relationship between innovation and the success of the organization. The evidence that innovative organizations are more successful is overwhelming [Bain 1956, Porter 1983]. It is therefore not surprising that innovation is seen as one of the most important processes in the organization. The importance originates not only from the organization's ability to develop products with unique features and therewith improve its competitive position, but also from the organization's ability to respond to changes in the environment threatening its existing competitive position.

Although the former proactive implementation of innovation is often the organization's intention, and the more glorious implication of innovation, the latter, reactive implementation represents more widely the context of innovation in organizations. There is also overwhelming evidence that many organizations have problems with innovation. In order to obtain a better understanding of these problems it is important to study the innovation process and its characteristics.

The innovation process is not necessarily similar in every organization and it depends on the type of activities that the organizations pursue. This study focuses on the innovation processes in Technology Intensive Organizations (TIOs) and more in particular TIOs active in High Tech industries like the semiconductor and material sciences industry. In these TIOs technology development plays an important role in the innovation process because technology provides the functionality of the product or process.

However, the technology development processes is often not considered as a part of the innovation process. In general there is more emphasis is on the New Product Development (NPD) process and the technology development process captured under the 'fuzzy front-end' of the NPD process. However, some contributions in literature indeed emphasize that the Technology Development process is not only important, but also hard to manage and quite different from the NPD process. This study supports the latter notion about the technology development process and intends to contribute to a better understanding of the technology development process, its role in the innovation process and how it is managed.

B. Problem definition

The technology development process is not well described in literature which is noteworthy because technology becomes more and more important for new products. The tendency is that products not only comprise more technologies, but also the manufacturing processes become more reliant on multiple technologies. It is expected

that this increasing complexity and integration of product and process technologies will continue. The increasing complexity implies having access to technology becomes more important. Access can be realized by licensing, technology acquisitions or by in-house developments.

As a result of the higher level of integration of technologies in products, it becomes more difficult for organizations to own all the required product and process technologies. While licensing and trading technologies provides more external access, one can argue that owning and developing the core technologies of the products or processes remains crucial to maintain a strong competitive position. Therefore, the development of technologies will be important for Technology Intensive Organizations, now and in the future.

Cooper argues that technology development processes are very important for the prosperity of the organization and that these processes are in general 'mishandled' by applying NPD methods to it [Cooper 2006]. Cooper proposes to apply an adapted 'Stage-Gate' process to the Technology Development process where the process is broken down in a flow where important decision points are represented by gates and the activities prior to these gates are defined as stages. This approach is not disputed but there are two issues which are not well addressed.

Firstly, during the development activities that Cooper identifies as stages, many decisions are made that 'do not make it to the gate'. It is recognized that the technology developments process requires gates, especially at a management level in order to decide on resources supporting the process. Because technology development is, in general, a costly and long lasting process it requires a lot of management support to progress.

However, at the operational level technology developers make all kind of decisions in order to make progress during the 'stages' of the process. These decisions definitely have impact on the outcome of the process and are therefore at least equally important to consider. The 'Stage-Gate' approach assumes that progress is made in the 'Stages' but how it is made is not discussed nor defined.

Secondly, the 'stage-gate' process does not take into account the notion that technology development is subject to a certain path dependency. This notion is based on numerous contributions in several bodies of literature: scientific discovery [Kuhn 1972], [Klahr & Simon 1999], economics [Nelson & Winter 1981], Organizational change [Van de Ven & Poole 1995] and cognition [Garud & Rappa 1999].

An important aspect is how the organization is operating while following a path. Possibly even more interesting is the question "What happens if an organization realizes that following the current path is not sufficient enough to meet the organizational goals that have been set?" These different modes, following the path versus breaking with the path, can be identified with the difference between evolutionary/equilibrium versus revolutionary/punctuated technology developments.

Summary

This distinction is not taken into account in the 'stage-gate' approach, while the impact on the organization can be very different. These two omitted issues will be particularly addressed in this thesis.

C. Research questions

The first research question is related to the technology development process and its relationship to product development and scientific discovery:

What are the characteristics of the technology development process in general and in comparison to the product development process and the scientific discovery process?

Technology developments that follow a certain path progress in equilibrium, require only evolutionary changes, and have limited impact on the organization. However, technology developments which require a change of path are considered to be much more radical to the organization. There are at least five aspects that need to be understood about a path change. Firstly, it is important to understand how the organization resists against a path change. Secondly, how is a path change initiated? And thirdly, how is the organization adapting to this path change.

These three aspects are addressed in the second research question: What are the processes and drivers at several levels in the organization, prior, during and after a technology path change?

The fourth aspect is finding the alternative path: How are alternative technology-paths identified, evaluated and selected? And, the fifth aspect is related to the required changes that are necessary to reach the alternative technology path: What are effective management techniques to manage decisions related to technology path change and the associated organizational changes?

D. The Technology Development process

The framework presented in Chapter 2 comprises the following four sub-processes of the technology development process: knowledge processes, change processes, problem solving processes and organizational processes

Knowledge processes: Technology can be seen as the embodiment of knowledge, indifferent whether it is scientific, explicit or tacit knowledge. Theoretical knowledge alone is not enough to obtain a technology; it requires practical knowledge or 'know how' to create a 'construct' that embodies the theoretical principles. Also it is assumed that for technology development in an organizational context, knowledge is generated [Nonaka 1994], disseminated [Berends 2003] and integrated [Grant 1996]. Furthermore, technological knowledge is generated by problem solving cycles, alike

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scientific knowledge [Popper 1970]. This generation process is considered to be an individual process [Popper 1970, Polanyi 1962, Nonaka 1994].

Change processes: Technology developments tend to change according to punctuated equilibrium process [Pettigrew 1985, Gersick 1991]. Very similar to scientific developments, evolutionary technology development tends to follow a certain predefined trajectory or paths, while revolutionary or radical technology developments are characterised by path-breaking activities [Kuhn 1970, 1977]. The notion that technology development is following an existing path can be identified with an equilibrium state where the organizational changes are small and gradual.

The punctuated periods where radical technology development takes place, resulting in breaking the existing path, may result in much more radical organizational changes. The skills, knowledge and capabilities the organization developed to operate along the existing path become less relevant or even meaningless and in order to operate along a new path, new skills, knowledge and capabilities are required that can be radically different from the previously developed ones.

Problem solving processes: Knowledge generation in context of new technology development is ultimately a process that takes place in the human mind, and is related to human problem solving. This individual knowledge generation process should be placed in the context of ongoing group processes and of the characteristics of the organization. The goal state in the problem solving cycles is very similar to the teleological change process as described by Van de Ven and is expected to play an important role in steering the problem solving cycles [Ven 1995].

The problem cycle is part of a broader decision making process. This process is related to the problem definition, goal state definition, the search strategy, and test strategies. These decisions are made on the basis of existing information and a stream of new information originating from the problem solving cycles.

Organizational processes: The justification to view technology development as a distinct organizational process can be based on a few contributions in literature. Cooper pointed out that technology development processes are different from other development processes and deliver new knowledge, new technology, or a new technical capability. The process comprises fundamental research projects, science projects, basic research, and often technology platform projects. [Cooper 2006]. Cooper sees Technology Development projects as a type of meta-projects leading to multiple commercial projects and new product platforms. This suggests that technology development processes can be seen a distinct organizational process.

Another way to look at the technology development process is to consider the so-called technological options that are initiated by the Generation of Technological Option (GTO) stage characterized by a divergent process where numerous options are

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created. This stage is followed by a convergent process - the Selection of Technological Option (STO) stage where various options are benchmarked and selected for further developments. In this stage the number of options is reduced. This stage is followed by an Integration of Technological Option (ITO) stage where various options are combined in order to test the combined functionality. And finally, the Deployment of Technology Option stage represents the integration of a technological option into a product. The stages are forming the TO-model that is described in more detail in Chapter 3.

E. Collective Frame of Reference

Based on the case study research reported in Chapters 4 and 6, several patterns have been observed that appeared to be decisive on the outcome of the technology development process. These patterns are related to a phenomenon that has been identified as Collective Frame of Reference, which can be described as:

Collective Frame of Reference (CFR) is a set of beliefs that is shared within a group and/or an organization. This belief is not necessarily justified like knowledge, and can be based on shared intuition, experiences, cultures and perceptions. The CFR can propagate through groups and across organizational boundaries.

In summary the following was observed:

- Coherent, coordinated activities and incoherent, uncoordinated activities coincide with the presence and absence the Collective Frame of Reference of the group.
- The presence of a strong Collective Frame of Reference keeps the group focused on its activities and allows for coordinated problem solving routines with a CFR based goal state.
- The absence of the CFR initiates incoherent and uncoordinated activities and this results in uncoordinated problem solving routines were the goal state is set based on individual beliefs.
- Propagation of the CFR is based on influencing individual beliefs and takes place internally, within the group, laterally towards functional interdependent groups and vertically - either top-down, or bottom-up.

The strength of the CFR can be defined based on three types of CFR:

- Type 1: CFR is based on the notion that a crisis exist or that a particular, not well defined goal needs to be realized.
- Type 2: CFR is based on the notion that a certain goal state needs to be realized, without particular agreement on method to realize the goal state.
- Type 3: CFR is based on the notion that a certain goal state will be realized by well defined methods.

Collective Frame of Reference in Technology Developments

The CFR is seldom completely shared and not all individuals in an organizational structure fully conform to the CFR. From a management perspective this can be seen as an undesired situation; first order management techniques rely on a hierarchical structure where policies flow down and which are adopted smoothly. It is argued that a not fully adopted CFR helps in situations where radical changes need to be made.

The CFRs develop under the influence of interactions between management level and operational level and under the influence of internal and external factors. The internal factors include the following.

- Competences: The know-how to conduct certain processes.
- Technologies: The technological building blocks available to the firm, basically forming the technology paradigm.
- Past Experiences: An organization carries the burden of historic failures and successes. In case of failures it imposes a certain fear factor to the CFR.
- Past Strategies: Choices, made in the past, impose path dependency on technology development.

These internal factors constitute in a paradigm that is related to the CFR. It is not only about the technological paradigms, but also about the routines, knowledge and skill sets that are present within an organization that constitute the paradigm of the organization. Successes and failures contributed to these paradigms and this is a burden that comes with the maturity of the organization.

The external factors contributing to the development of a CFR include the following.

- Market developments: The market developments obviously influence the CFR.
- DESTEP factors: The Demographic, Ecological, Social-Cultural, Technological, Economic and Political factors influence CFR development.
- Competitive developments: Competition can be considered as very significant in the development of CFRs with respect to prospective technologies.
- External technological factors: The upcoming and downfall of technologies that are directly or indirectly related to the technology base of the organization will definitely influence the CFR of the firm.

These factors are more about perceptions rather than objective facts.

To conclude, four psychological and social factors are suggested that constitute to the CFR.

- Values: The values of a group or individual impact on the CFR even as actors are unaware of the influence of this factor on their acting.
- Individual Beliefs: The individual beliefs impact on the CFR and tend to be more volatile than values.
- Self Esteem: The self esteem is a perceptual view on the value that an individual or group has for its environment.

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- Risk perception: The perception of risks impacts the Collective Frame of Reference and can be associated with entrepreneurial attitudes of a group or individual.

These factors determine not only the coherency of the groups and the confidence levels contributing to the CFR, but also the course of action in the absence of a CFR.

F. Management implications

The management implications regarding the Collective Frame of Reference are summarized in the following management actions:

Gathering and providing objective information: Managing the flow of information is considered a very important factor to influence the CFR. Providing a flow of objective information and providing the means to process this data in an efficient fashion will help for the 'good' and for the 'bad'.

On the one hand, if the objective information is interpreted by the individuals in such a way that the CFR is reinforced, this can be considered as 'good' - the organization is doing well while following the existing paradigm and the members of the organization have the impression that this is sustainable. On the other hand, if the objective information weakens the CFR, it can be expected that this is for good reasons- the members of the organization have the impression that following the existing paradigm is not sustainable and that change is required.

Connect to the external networks: Connection to external networks provides useful information about the technological capabilities of the organization. Monitoring trends in technology allows the organization to better anticipate the 'sudden' external changes. These networks are comprised of scientific networks, supplier networks, user networks and other networks, for example, such as economical think-tanks which can provide information about trends in future needs. Management of an organization can influence the CFR by assuring that professionals in the organization are connected to the relevant networks.

Stimulate Confidence: Many organizations are aware that celebrating success is important to stimulate the confidence level in the organization. Presenting the success stories internally is important but for the CFR it is also important that previous failures are well understood. An organization tends to interpret failures as evidence that everything outside the comfort zone of the organization is doomed. The issue is that radical technology development results in one or two successes out of ten attempts and therefore easily can be interpreted as a waste of time and money. An organization has to manage these failures in such way that new opportunities are still considered despite the build-up of evidence that technology developments can only go wrong.

Allowing non-conformist behavior: This may be the most difficult factor to manage as the traditional management techniques assume that all members of the organization follow the strategy and contribute to the goals that are set by the management. Any behavior that is not contributing or sometimes even contradictory to the strategy can be seen easily as unwanted behavior. However as this non-conformist behavior is a source of organizational change, it should not be excluded by the organization.

G. Conclusions

The main conclusions of this study are:

- The technology development process is positioned between the scientific discovery process and the product development process.
- A technological option is an artefact or construct that often is based on a scientific principle and which can provide a certain product or process function.
- Based on the Technological Option model, the technological option passes through four phases:
 - o A generation phase where an artefact is created, and which demonstrates certain functionality.
 - o A selection phase where the functionality of the artefact is competing with alternative options,
 - o An integration phase where a specific option and its functionality is integrated with other options.
 - o A deployment phase where the option is incorporated into a product in order to provide this product with certain functionality.
- Technology, like science develops along paths, governed by a paradigm, which provides evolutionary, more or less predictable improvements, punctuated by developments leading to new paradigms.
- The paradigm character of technology plays not only on a macro- and mesoscopic scale; it is also present within Technology Intensive Organizations.
- Radical or paradigm shifting technology development programs are hard to manage, unpredictable and require particular measures to weather short-term vs. long-term deliberations.
- Technology development can be characterized as 'evolutionary' if it progresses along a technology path.
- Technology development can be characterized as 'revolutionary' or 'radical' if it requires a paradigm shift.

Summary

- Both the evolutionary and revolutionary technology development in the organization is driven by the Collective Frame of Reference.
- A paradigm shift starts from and results in a recurring, cyclical phase, which represents an equilibrium state of the organization. The actual shift takes place in three phases. The first phase is the reorientation phase where the organization identifies new technology paradigms to consider and start acquiring knowledge of paradigms that are thought to be suitable to provide useful and relevant technology options. In the second phase the organization takes all the decisions that are required to adopt the new paradigm. And in the third phase, the organization implements decisions that have been made.
- The development of the CFR changes throughout the paradigm shift; in the recurring or cyclical phase the CFR drives the focus on recurring tasks that develop the current technology option.
- The breaking of the technology paradigm is assumed to be sparked by an individual who develops a belief that opposes the shared belief that keeps the organization on the current technology paradigm.
- Once this individual is confident to share her or his beliefs with others, this belief may or may not be accepted by others.
- If the non-conforming belief holds and gains foothold at the decision makers in the organization, a wider reorientation process is initiated to obtain knowledge about alternative technology paths.
- The selection of an alternative technology paradigm is, in general, not a single decision point, but consists of a chain of decisions on sub aspects of the transition.
- Managing the flow of information is considered a very important factor to influence the CFR.
- Connecting to the external networks is important, not only because it can provide objective information as discussed above, but also because it provides access to external knowledge that is, or will become, important for the reorientation process.
- Stimulating Confidence is important for the balance between the CFR and non-conforming behavior.
- Allowing non-conformist behavior as it is a source of change in the organization.

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Samenvatting (in Dutch)

A. Inleiding

De relatie tussen innovatie en het succes van de onderneming is uitgebreid beschreven in verschillende stromen van de literatuur. Het bewijs dat innovatieve ondernemingen succesvoller zijn is overweldigend [e.g. Bain 1956, Porter 1983]. Het is daarom dan ook niet verbazingwekkend dat innovatie wordt gezien als een van de belangrijkste processen in de organisatie. Het belang is niet alleen gerelateerd aan het vermogen van de onderneming om producten met unieke eigenschappen te ontwikkelen die de competitieve positie versterken, maar is ook gerelateerd aan het vermogen van de onderneming om te reageren op veranderingen die de competitieve positie kunnen waarborgen. Hoewel de eerste genoemde, pro-actieve implementatie van innovatie, vaak de onderneming's intentie is en vaak wordt gezien als de meest glorieuze vorm van innovatie, de laatst genoemde reactieve implementatie sluit meer aan bij de praktijk van ondernemingen.

Er is ook overweldigend bewijs dat vele ondernemingen problemen hebben met innovatie. Het is belangrijk om het innovatie proces en de eigenschappen nader te onderzoeken om een beter begrip te krijgen van deze problemen. Het innovatie proces is niet noodzakelijkerwijs hetzelfde in elke organisatie en is afhankelijk van het type van activiteiten die de organisatie nastreeft. Deze studie beschouwt de innovatie processen in Technologie Intensieve Organisaties (TIOs) en in het bijzonder TIOs die actief zijn in de High Tech industrie, met toepassingen van halfgeleiders en geavanceerde materialen. In deze TIOs, speelt technologie ontwikkeling een belangrijke rol omdat technologie de functionaliteit van het product bepaald. Echter het technologie ontwikkelingsproces wordt vaak niet gezien als onderdeel van het innovatie proces. In het algemeen wordt er meer nadruk gelegd op het Nieuw Product Ontwikkeling (NPO) proces gelegd, terwijl technologie ontwikkeling vaak wordt gevat onder de noemer van het 'fuzzy front-end' van het NPO proces. Recentere bijdrage in de literatuur benadrukken echter dat het Technologie Ontwikkelingsproces niet alleen belangrijk is maar ook moeizaam te managen is en duidelijk anders is dan het NPO proces. Deze studie onderschrijft deze notie over de technologie ontwikkeling proces en streeft ernaar om een beter begrip te krijgen van het proces, de relatie met het innovatie proces en hoe het kan worden gemanaged.

B. Probleem definitie

Het technologie ontwikkelingsproces is niet uitgebreid beschreven in de literatuur, wat eigenlijk opvallend is gezien het feit dat technologieen een prominentere rol spelen voor nieuwe producten. De trend is niet alleen dat producten uit meerdere complexe technologieen bestaan, maar ook dat de fabricage processen om die producten te maken complexer en meer afhankelijk van technology worden. De verwachting is dat

deze toenemende complexiteit en integratie van product- en fabricage technologieën zal voortzetten. Daarmee wordt de toegang tot technologie in toenemende mate belangrijk. De toegang tot technologie kan verkregen worden middels licenties, technologie acquisities of door eigen ontwikkeling. Door de toenemende integratie van meerdere technologieën wordt het moeilijker voor een organisatie om alle toegepaste product- en fabricage technologieën te ontwikkelen en in eigen beheer te hebben. Hoewel licenties en het aankopen van technologieën hier kan helpen kan men stellen dat de ontwikkeling van de kern technologieën van cruciaal belang is om een sterke competitieve positie van de organisatie te waarborgen. Het is daarom te verwachten dat de ontwikkeling van technologieën belangrijk blijft voor Technologie Intensieve Organisaties, nu en in de toekomst. Inderdaad stelt Cooper dat technologie ontwikkeling erg belangrijk is voor het welzijn van de organisatie, maar ook stelt hij dat deze processen in het algemeen worden ‘mishandeld’ door de toepassing van New Product Ontwikkelings methodes [Cooper 2006]. Cooper zelf stelt voor om een aangepast ‘Stage-Gate’ proces toe te passen waarin het Technology Ontwikkelingsproces wordt opgebroken in een structuur waarin belangrijk beslissingspunten worden gedefinieerd, voorafgegaan door specifieke ontwikkelings activiteiten. Deze aanpak wordt op zich zelf niet ter discussie gesteld maar er zijn twee aspecten die niet specifiek in acht worden genomen.

Allereerst moet worden gesteld dat tijdens de ontwikkelactiviteiten vele beslissing worden genomen die het niet noodzakelijkerwijs onderdeel vormen van de ‘Gate’. Het wordt zeker erkend dat ‘gates’ van belang zijn, in het bijzonder voor het management, om te beslissen over het alloceren van mankracht en financiën om de voortgang te waarborgen. Deze betrokkenheid van het management is zeer belangrijk speciaal omdat technologie ontwikkelingsprocessen langdurig en kostbaar zijn. Echter de beslissingen die worden gemaakt door de technologie ontwikkelaars tijdens de ontwikkelactiviteiten hebben grote invloed op de voortgang. Gezien het feit dat deze beslissingen grote invloed hebben op de uitkomst van het proces, moet worden geconcludeerd dat deze minstens zo belangrijk zijn als de management beslissing. De ‘Stage-Gate’ aanpak gaat ervanuit dat voortgang wordt gemaakt in de ‘stages’ van het proces, maar hoe deze voortgang wordt gemaakt wordt niet in acht genomen noch gedefinieerd.

Ten tweede wordt in de ‘stage-gate’ aanpak niet in acht genomen dat technologie ontwikkeling onderworpen is aan een zekere pad-afhankelijkheid. Deze notie is gebaseerd op de verschillende bijdragen in de meerdere stromen van de literatuur: bijvoorbeeld in Wetenschappelijke Ontdekkingen [Kuhn 1972], [Klahr & Simon 1999] Economie [Nelson & Winter 1981], Organisatie Veranderingen [Van de Ven & Poole 1995] and Cognitie [Garud & Rappa 1999]. Een belangrijk aspect is hoe de organisatie opereert terwijl het een technologie pad volgt, maar wellicht interessanter is: Wat gebeurt er als de organisatie niet langer het pad kan volgen om de doelstellingen te realiseren? Deze twee verschillende modes; het volgen van een technologie pad versus het breken met een technologie pad, kan worden geïdentificeerd met enerzijds een

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evolutionaire/evenwichtige technologie ontwikkeling en anderzijds een revolutionaire/abrupte technologie ontwikkeling. Dit onderscheidt wordt niet in acht genomen in de 'stage-gate' aanpak, terwijl de impact op de organisatie dramatisch verschillend kan zijn.

Deze twee hiaten in de 'stage-gate' aanpak worden specifiek in dit proefschrift behandeld.

C. Onderzoeksvragen

De eerste onderzoeksvraag is gerelateerd aan het technologie ontwikkelproces en de veronderstelde relaties met het nieuw product ontwikkelingsproces en het wetenschappelijke ontdekkingsproces.

Wat zijn de karakteristieke eigenschappen van het technologie ontwikkeling proces, in het algemeen en in verhouding met het product ontwikkelingsproces en het wetenschappelijke ontdekkingsproces?

Een technologie ontwikkeling waarbij een bepaald pad wordt gevolgd, heeft een evenwichtige voortgang, resulteert in uitsluitend evolutionaire veranderingen en heeft een beperkte impact op de organisatie. Echter technologie ontwikkelingen die een pad wijziging ondergaan worden verondersteld een veel grotere impact te hebben op de organisatie. Er zijn minstens vijf aspecten die begrepen moeten worden van technologie pad wijzigingen.

Allereerst, is het van belang dat wordt begrepen hoe een organisatie weerstand biedt tegen padwijzigingen. Ten tweede, moet worden begrepen hoe een padwijziging wordt geïnitieerd. Ten derde moet worden begrepen hoe een organisatie zich aanpast na een padwijziging. Deze drie aspecten leiden tot de tweede onderzoeksvraag:

Wat zijn de processen en drijfveren die spelen op verschillende niveaus van de organisatie, voor, tijdens en na een technologie padwijziging?

Het vierde aspect is gerelateerd aan het vinden van een alternatief pad.

Hoe worden alternatieve technologie paden geïdentificeerd, geëvalueerd en geselecteerd?

Het vijfde aspect is gerelateerd aan de noodzakelijke veranderingen die benodigd zijn om het alternatieve pad te gaan volgen:

Wat zijn effectieve management technieken voor beslissingen betreffende technologie padwijzigingen en de daaruitvolgende organisatieveranderingen?

D. Het technologie ontwikkelproces

Het theoretisch raamwerk dat in hoofdsuk 2 wordt gepresenteerd bestaat uit de volgende sub-processen van het technologie ontwikkeling proces: Kennisprocessen, Veranderingprocessen, Probleemoplossingsprocessen en Organisatieprocessen.

Kennisprocessen: Technologie kan gezien worden als een belichaming van kennis, ongeacht of dat wetenschappelijke, expliciete of impliciete kennis is. Alleen theoretische kennis is niet voldoende om een technologie te creëren; ook praktische kennis of 'know how' is benodigd om een construct te maken die de technologie omvat. Het is aannemelijk dat voor technologie ontwikkeling binnen de context van een organisatie kennis gegenereerd [zie bijv. Nonaka 1994], verspreid [zie bijv. Berends 2003] en geïntegreerd [zie bijv. Grant 1996] dient te worden. Verder wordt gesteld dat technologisch kennis wordt gegenereerd door problem oplossingscycli, gelijk aan wetenschappelijke kennis [zie bijv. Popper 1970, Polanyi 1962, Nonaka 1994]. Dit generatieproces wordt beschouwd als een individueel proces.

Veranderingsprocessen: Technologie ontwikkelingen lijken te veranderen volgens een abrupt/evenwicht proces [zie bijv. Pettigrew 1985, Gersick 1991]. Zeer gelijkend op wetenschappelijke ontwikkelingen, volgen evolutionaire technologie ontwikkelingen een bepaald voorgeschreven traject of ook wel pad, terwijl revolutionaire ontwikkelingen worden gekarakteriseerd door pad wijzigingen [zie bijv. Kuhn 1970, 1977]. De notie is dat wanneer technologie ontwikkelingen een bepaald pad volgen, dit geïdentificeerd kan worden als een evenwichtstoestand waarbij de organisatorische veranderingen beperkt en gradueel zullen zijn. Deze evenwichtstoestand wordt soms abrupt onderbroken door een periode waarin het technologie pad wordt gewijzigd, hetgeen leidt tot radicalere organisatieveranderingen. De vaardigheden, kennis en capaciteiten die de organisatie heeft ontwikkeld tijdens het volgen van het bestaande pad, worden minder relevant en soms zelfs waardeloos, terwijl het volgen van een alternatief pad nieuwe vaardigheden, kennis en capaciteiten vergt, die radicaal anders kunnen zijn van de vorige.

Probleem oplossingsprocessen: Kennis generatie binnen de context van technologie ontwikkeling is uiteindelijk een process dat plaatsvindt in het menselijke brein en is gerelateerd aan het Menselijk Probleem Oplossingsproces. Dit individuele kennis generatieproces zal moeten worden gezien binnen de context van continue groepsprocessen en de karakteristieken van de organisatie. De doeltoestand van de probleemoplossing cycli lijkt erg veel op het teleologische veranderingsproces zoals beschreven door Van de Ven en aangenomen is dat deze doeltoestand een belangrijke rol speelt in het sturen van de probleemoplossingcycli [Ven 1995]. De probleemoplossingcyclus is onderdeel van een breder besluitvormingsproces en is gerelateerd aan de probleemdefinitie, doeltoestand, zoekstrategie en verificatie

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strategies. Deze besluiten worden gemaakt op basis van bestaande informatie en de continue stroom van nieuwe informatie die voortkomt uit de probleemoplossingcyclus.

Organisatorische processen: De rechtvaardiging om technologie ontwikkeling te beschouwen als een specifiek organisatorisch proces is gebaseerd op een aantal bijdragen in de literatuur. Cooper stelt dat het technologie ontwikkelproces anders is dan product ontwikkelprocessen en nieuwe kennis, technologie en capaciteiten opleveren. Het proces bestaat o.a. uit fundamenteel onderzoek, wetenschappelijke projecten en leidt vaak tot nieuwe platformen [Cooper 2006]. Cooper ziet Technologie ontwikkeling als een soort meta-project, waaruit een keten van nieuwe commerciële projecten en nieuwe product platformen voortkomt. Deze unieke eigenschappen alleen al geeft de rechtvaardiging om technologie ontwikkeling te zien als een specifiek organisatorisch proces.

Een andere wijze om het technologie ontwikkelingsproces te beschouwen is om het proces van de generatie, selectie, integratie en toepassing van de technologie opties te bestuderen. De Generatie van Technologische Opties (GTO) fase is een proces stap waarbij het aantal mogelijke opties wordt uitgebreid en het is in wezen een divergent proces waarbij meerdere technologische opties worden gegenereerd die potentieel dezelfde functionaliteit kunnen bieden. Deze fase wordt gevolgt door de Selectie van Technologische Opties (STO) fase, waarin het aantal opties wordt teruggebracht door het toepassen van verschillende criteria die van belang zijn voor de uiteindelijke gewenste functionaliteit. Dit is een convergent proces waarbij het totale aantal beschikbare opties en mogelijkheden wordt gereduceerd. De volgende fase is de Integratie van Technologische Opties (ITO) fase, waarbij combinaties van technologische opties worden bestudeerd op functionaliteit. Ook in deze fase wordt het aantal opties verder teruggebracht. Tot slot wordt Toepassing van Technologische Opties (TOO) fase doorlopen waarbij een combinatie van technologische opties wordt toegepast in een product. De fase van bovengenoemd model zijn in meer detail beschreven in Hoofdstuk 3.

E. Collectief Referentie Kader

Gebaseerd op de geval-studies beschreven in Hoofdstuk 4 en 6, zijn verscheidende patronen geobserveerd die ogenschijnlijk bepalend waren voor de uitkomst van het technologie ontwikkelingsproces. Deze patronen zijn gerelateerd aan een fenomeen dat geïdentificeerd is als Collectief Referentie Kader (CRK) hetgeen beschreven kan worden als:

Het Collectief Referentie Kader is een set van overtuigingen die worden gedeeld binnen een groep en/of een organisatie. De overtuigingen zijn niet noodzakelijkerwijs gerechtvaardigd (zoals bij kennis) en kunnen zijn gebaseerd op

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gedeelde intuïtie, ervaring, cultuur en percepties. De CRK kan prolifereren binnen groepen en over organisatorische grenzen.

Samenvattend is het volgende geobserveerd:

- Coherente, gecoördineerde activiteiten en incoherente ongecoördineerde activiteiten komen overeen met de aanwezigheid dan wel afwezigheid van het Collectief Referentie Kader van een groep.
- De aanwezigheid van een sterke Collectief Referentie Kader houdt de groep gefocuseerd op het volgen van het huidige pad en staat gecoördineerde probleem oplossing cycli toe, waarbij de CRK de doeltoestand bepaalt.
- De afwezigheid van de CRK initieert incoherente en ongecoördineerde activiteiten die zich uiten in ongecoördineerde probleem oplossing routines waarbij de doeltoestand is gebaseerd op individuele overtuigingen.
- Propagatie van de CRK is gebaseerd op de beïnvloeding van individuele overtuigingen, hetgeen plaatsvindt binnen de groep, lateraal tussen groepen, en verticaal opwaarts of neerwaarts in de hiërarchie.

De sterkte van de CFR kan worden uitgedrukt in de vorm van typologieën:

- Type 1: Een CRK is gebaseerd op de notie dat een crisis bestaat en opgelost moet worden, of op een ander algemeen doel.
- Type 2: Een CRK is gebaseerd op de notie dat een bepaalde doeltoestand moet worden gerealiseerd, zonder dat er overeenstemming is over een specifieke methode om de doelstand te realiseren.
- Type 3: Een CRK is gebaseerd op de notie dat the doeltoestand zal worden gerealiseerd volgens een overeengekomen methode.

De CRK wordt zelden volledig gedeeld en niet alle individuen in de organisatie conformeren aan de CRK. Vanuit een management perspectief zal dit gezien worden als een ongewenste situatie, omdat eerste orde management technieken gebaseerd zijn op een hiërarchische structuur waarbij directieven neerwaarts afdalen en waarvan verwacht wordt dat ze worden opgevolgd. Er kan echter gesteld worden dat een niet volledig aangenomen CRK juist kan helpen in situaties waarbij radicale veranderingen nodig zijn.

De CRK ontwikkelt zich onder invloed van interacties tussen het management level en het operationele level en onder invloed van interne en externe factoren. De interne factoren betreffen de volgende:

- Competenties: De 'know-how' om bepaalde processen uit te voeren.
- Technologieën: De technologische bouw blokken die aanwezig zijn binnen een organisatie en die in wezen het technologie paradigma vormen.

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- Gewezen Ervaringen: Een organisatie draagt de last historische catastrofes en successen met zich mee.
- Gewezen Strategien: Keuzes gemaakt in het verleden voeren door op de keuzen voor de toekomst en resulteert in een pad afhankelijkheid.

Deze factoren resulteren in een paradigma dat gerelateerd is aan het CRK. Het gaat hierbij niet uitsluitend om het technologisch pad maar ook om de routines, de kennis en de vaardigheden die aanwezig zijn in een organisatie en bijdragen aan een organisatorisch paradigma. Successen en catastrofes dragen bij aan het paradigma en deze last komt met de jaren.

De externe factoren die bijdragen aan de CRK zijn de volgende:

- Marktontwikkelingen: De marktontwikkelingen dragen bij aan de mogelijkheden en bedreigingen van de organisatie en beïnvloeden de CRK.
- DESTEP factoren: De Demografische, Ecologische, Sociaal-Culturele, Technologische, Economische and Politieke factoren beïnvloeden de ontwikkeling van het CRK.
- Competitieve ontwikkelingen: Competitie kan worden gezien als een belangrijke factor voor het CRK.
- Externe technologische factoren: De opkomst en neergang van technologieën die direct of indirect zijn gerelateerd aan de technologie basis van de organisatie beïnvloeden de CRK.

Deze factoren zijn meer gerelateerd aan percepties dan aan objectieve feiten.

Tenslotte zijn er vier psychologische en sociale factoren die bijdragen aan de vorming van de CRK.

- Waarden: De waarden van de groep of het individu heeft (onbewust) een invloed op de CRK
- Individuele Overtuigingen: De individuele overtuigingen van het individu beïnvloed de CRK en deze zijn meer fluide dan de waarden.
- Zelfvertrouwen: Het zelfvertrouwen is een perceptie van de waarde van een groep of individu voor de omgeving. Zelfvertrouwen beïnvloed sterk de zekerheid waarmee beslissingen worden genomen.
- Risico perceptie: De perceptie van risico's beïnvloed de CRK en kan geïdentificeerd worden met het ondernemerschap van de groep of het individu.

Deze factoren bepalen niet alleen de coherentie van de groep en het zelfvertrouwen van de groep, maar ook wat er gebeurt als de CRK verdwijnt.

F. Management implicaties

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De managementimplicaties betreffende Collectief Referentie Kader zijn samengevat met de volgende management acties:

Het verzamelen en verstrekken van objectieve informatie: Het managen van de informatie stromen wordt als zeer belangrijk beschouwt voor het beïnvloeden van de CRK. Het verstrekken van informatie en de mogelijkheden om deze efficiënt te verwerken komt de CRK ten goede of ten kwade. Aan de ene kant kan de verstrekte informatie door de individuen op zodanige wijze worden geïnterpreteerd dat het bijdraagt aan een versterking van het bestaande CRK. Menigeen zal dit als 'goed' omschrijven omdat het aangeeft dat de algemene indruk is dat de organisatie er goed aan doet om het huidige pad te blijven volgen. Anderzijds kan de objectieve informatie er toe leiden dat het CRK afbrokkeld en dat een crisis ontstaat waarin het onduidelijk is wat de juiste koers is voor de organisatie. Hoewel dit als slecht kan worden gezien, kan ook worden gezegd dat de organisatie leden het idee hadden dat de organisatie niet langer kan voortbestaan en dat de koers moet veranderen.

Aansluiting bij externe netwerken: Aansluiting bij externe netwerken geeft toegang tot informatie die van belang kan zijn voor het inschatten van de status van de huidige technologie. Het monitoren van trends in technologie geeft de mogelijkheid om beter te anticiperen op 'plotselinge' externe ontwikkelingen. Deze netwerken omvatten wetenschappelijke netwerken, leveranciersnetwerken, gebruikersnetwerken en andere netwerken zoals 'think tanks' en kunnen vanuit diverse beschouwingen een idee geven van de trends en ontwikkelingen. Het management kan de CRK beïnvloeden door te waarborgen dat de professionals in de organisatie aangesloten zijn op een breed scala van netwerken.

Stimuleren van zelfvertrouwen: Veel organisaties zijn zich bewust dat successen moeten worden gevierd en op deze wijze het zelfvertrouwen gunstig beïnvloeden. Het intern zichtbaar maken van successen is belangrijk, maar voor de CRK is het ook belangrijk dat de catastrofes goed begrepen zijn. Organisaties neigen ernaar om catastrofes te interpreteren als het bewijs dat alles wat buiten het gebruikelijke stramien ligt gedoemd is om te mislukken. Het probleem met deze houding is dat radicale technologie ontwikkeling een lage kans van slagen heeft en daarmee gemakkelijk als een verspilling van tijd en geld kan worden gezien. Een organisatie moet deze catastrofes goed managen zodat er geen overkombare barrières worden gecreëerd die de organisatie passief maakt.

Toestaan van anti-conformisme: Het toestaan van anti-conformisme is wellicht een van de moeilijkste aspecten van het managen van de CRK omdat iedereen wordt geacht bij te dragen aan de doelstellingen die de organisatie heeft gesteld. Ieder gedrag dat niet bijdraagt aan de strategie of soms zelfs de strategie tegenwerkt kan gemakkelijk gezien worden als contra-productief. Er kan echter ook worden gesteld dat anti-conformisme

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een bron is van organisatorische veranderingen waarvan de waarde wordt gezien als de organisatie een crisis ontmoet.

G. Conclusies

De belangrijkste conclusies van deze studie zijn:

- Het technologie ontwikkelingsproces kan worden gepositioneerd tussen het wetenschappelijke ontdekkings proces en het nieuw product ontwikkelingsproces.
- Een technologische optie is een artifact of construct dat vaak is gebaseerd op een wetenschappelijk principe en hetgeen een bepaalde product- of fabricage functie kan leveren.
- Volgens het TO model doorloopt een technologie optie de volgende vier fasen:
 - o Een generatie fase waarin de optie met een bepaalde functionaliteit wordt gecreeerd.
 - o Een selectie fase waarin verscheidene opties worden vergeleken en geselecteerd op basis van wens-criteria.
 - o Een integratie fase waarin verschillende combinaties van opties onderzocht en worden geselecteerd.
 - o Een toepassings fase waarin de optie wordt verwerkt in een nieuw product.
- Technologie ontwikkelt zich net als de wetenschap meestal langs een gedefinieerd pad dat door een paradigma wordt beheerst, hetgeen resulteert in graduele ontwikkelingen. Dit patroon wordt afgewisseld met abrupte ontwikkelingen waarbij een nieuw pad wordt gezocht gedomineerd door een nieuw paradigma.
- Het paradigma karakter van technologie speelt niet alleen een rol op een macroscopische en mesoscopische schaal maar ook binnen Technologie Intensieve Organisaties.
- Radicale technologie ontwikkelingen zijn moeilijk te managen, onvoorspelbaar en moeten weerstand bieden tegen ongunstig uitvallende korte versus lange termijn afwegingen.
- Technologie ontwikkeling kan als evolutionair gekarakteriseerd worden zodra een technologie pad wordt gevolgd.
- Technologie ontwikkeling kan als revolutionair of radicaal gekarakteriseerd worden zodra een technologie pad wijziging plaatsvindt.
- Evolutionaire en Revolutionaire technologie ontwikkelingen worden beiden gedreven door het Collectief Referentie Kader.
- Een paradigma wijziging begint met en eindigt met een wederkerende, cyclische fase, welke een evenwichtstoestand binnen de organisatie representeert. De eigenlijke wijziging vindt plaats middels drie fasen; de

reorientatie fase waarin de organisatie nieuwe paradigmas identificeert en daarover kennis verzamelt. In de daaropvolgende fase neemt de organisatie de beslissingen die nodig zijn om het nieuwe paradigma aan te nemen. In de derde fase wordt de wijziging geïmplementeerd.

- De ontwikkeling van het CRK wijzigt gedurende de paradigmawijziging, terwijl het CRK in de wederkerende of cyclische fases een vaste waarde is die de focus legt op de wederkerende taken die overeenkomen met het volgen van een technologie pad.
- Het wordt verondersteld dat een individu het wijzigen van een technologie paradigma initieert. Dit individu ontwikkelt een overtuiging die tegenovergesteld is aan de gedeelde overtuiging.
- Op het moment dat een individu zelfverzekerd genoeg is om zijn overtuiging te delen met anderen in de organisatie, kan deze overtuiging verder door de organisatie proliferen.
- Wanneer dit anti-conformisme wordt overgenomen en stand houdt bij de besluitvormers van de organisatie, wordt een bredere orientatie geïnitieerd met het doel om meer kennis over alternatieven te vergaren.
- Het selecteren van een alternatief technologie pad is in het algemeen niet gebaseerd op een enkel besluit, en omvat vele deelbesluiten die allen bijdragen tot de wijziging.
- Het managen van de informatie stromen wordt gezien als een belangrijke factor om het CRK te beïnvloeden.
- Aansluiting bij externe netwerken is belangrijk, niet alleen omdat het toegang biedt tot objectieve informatie, maar ook om het reorientatie proces te voeden.
- Het stimuleren van zelfverzekerdheid is belangrijk voor de balans tussen conformatie en anti-confirmatie aan het CRK.
- Het toestaan van anti-confirmatie creert een bron van organisatie veranderingen.

About the Author

About the Author

Cornelis (Cees) Draijer (1967) obtained his Bachelor degree in Business Engineering from the Fontys University of Applied Science and his Master degree in Applied Physics from the Eindhoven University of Technology. He started his professional career at the Philips Research Laboratories (NatLab) as a research scientist. Later after becoming part of the Philips Semiconductor Business Unit, he specialized in the development and design of Charge Coupled Device (CCD) imagers. Later in 2002, he continued these activities after his department was acquired by DALSA, a Canadian company. More recently in 2007, he moved with his family to the DALSA head quarters in Waterloo, Ontario, Canada, where he holds a technical marketing and program manager position. His main focus is on new imaging technologies and related new markets. While pursuing his professional career, he conducted a study towards the drivers behind the technology development process. This study resulted in this dissertation.

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