EXPLORING THE INNOVATION PHASE OF RADICALLY-NEW HIGH-TECH PRODUCTS

An investigation of two historical cases of AIDC technologies

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by

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Abstract

The transformation of a new technological principle into a marketable product usually signifies a long and risky route for organizations engaged in the commercialization of radically new high-tech products. New products often fail to make it to the market, are delayed for their market introduction, or are withdrawn shortly after their market introduction. The period that spans from invention to (first) market introduction of radically new high-tech products (i.e. the innovation phase) has been found to last on average ten years (Ortt, 2010). Furthermore, the duration of the innovation phase may significantly vary per product. Arguably, this duration is suspected to encompass several barriers and strategic interaction. This thesis explores the erratic nature of the innovation phase by asking “what are the key actors and factors that facilitate or hamper innovation?”, “how are these interrelated?”, and “what strategies can be derived for organizations?”.

The issue of successfully developing and commercializing innovative products pertains to a vast literature and several theoretical domains that have different units of analysis and orientation towards the innovation process. Although, theories propose different actors and factors as barriers and/or facilitators to bringing new technological products to the market, a comprehensive picture of how these actors and factors interact and influence the course of the innovation phase is lacking. This thesis argues that a more complete picture of the innovation phase can be achieved by synthesizing a wide range of notions from different theories. In turn, this can assist the process of devising more holistic innovation strategies.

For the purpose of this research, a two-phase methodological approach has been followed. The first phase consists of a literature review that selectively examines the fields of: Strategic Niche Management, Organizational Capabilities/Characteristics and Innovation, the Valley of Death in Innovation, and the Fuzzy Front End of Innovation. The project theorizes that the concepts presented by these theories can be better understood if categorized along three broad and separate but interrelated levels: (i) a macro-level that comprises the market environment within which transitions to new technological regimes take place; (ii) a meso-level that is composed by the organization that considers the commercialization of radically new technologies; and (iii) a micro-level that consists of the project within which a new product is developed. The examined theories emphasize interrelations among factors that are usually found at the same level of analysis. However, this study attempts to reveal interaction among factors both within and across these levels.

The integration of actors, factors, and interrelations is realized through the construction of a multi-level framework based on the distinction of the three aforementioned levels of interaction. The framework serves both as a static list of key influencing actors and factors, and for addressing interrelations among them. It is presumed that the same actors and factors can act as barriers and/or facilitators to innovation. Several simple mechanisms of interaction between factors are proposed, such as barriers reinforcing other barriers, or facilitators diminishing barriers. These mechanisms concern interaction among factors, both within and across levels. Consequently, more advanced mechanisms are derived, such as a chain of reinforcing barriers might create a negative feedback loop that possibly blocks radical innovation. A web consisting of barriers and facilitators that may have multiple causes and effects at the same time is

revealed. With regard to the interaction among actors, a systematic way of interrelating is more difficult because of their complex nature.

The framework is illustrated and refined in a second phase, with the investigation of two historical cases of Automatic Identification and Data Capturing (AIDC) technologies: Radio Frequency Identification and barcode. The analysis, which is based on secondary published documentation, enables not only the identification of several actors and factors, but also demonstration of interactions among factors and factors both within and across the distinguished levels. In addition, generic strategies for companies to cope with the innovation phase are derived as a result of empirical observations within the case studies.

The major outcome of the project is the multi-level framework to address key actors and factors, and interrelationships that influence the innovation phase. Macro-level factors include: Technological Factors, Economic Factors, Competition, Supply Networks, Infrastructure & Maintenance Networks, Social Networks, Psychological & Cultural Factors, Social & Environmental Effects, Government Policy, Legislation & Regulation (Laws, Standards and Rules), Institutional Risk, and Competition; Meso-level factors include: Scientific Knowledge and Firm-Specific Techniques, Technical Systems, Managerial Systems, Organizational Culture and Values, and Financial Resources; and Micro-level factors include: Opportunity, Product Concept & Definition, Project Planning, and New Product Development process. With regard to the actors, Macro-level actors include: Governments, Research Institutes, Universities, Industries, Policy-makers, Regulators, Suppliers, Providers of Complementary Products, Potential Users (Early Adopters), Scientists, and Autonomous Entrepreneurs; Meso-level actors include: (Network of) Companies-Developers, Top - management, Executives, and Consultants; and Micro-level actors include: Product Champions, Project Managers, and Project Teams.

Moreover, the emergence and influence of actors and factors within the case studies, indicated the following four key generic strategies for companies to deal with to the innovation phase: (i) Collaboration with other Knowledge Producing Institutions, (ii) Strategic Patent Acquisition, (iii) Working together with Potential Early Adopters, and (iv) Long-term Investment in Technology. These should not be viewed as competing alternatives, but, rather as mutually supporting options for firms that are engaged with development and/or commercialization efforts.

The overall findings suggest a rather complex landscape for organizations seeking the commercialization of radical high-tech products. The innovation phase is characterized by significant dynamics in terms of the actors involved with research and/or NPD projects. Moreover, the successful market introduction of new technologies is more likely to be determined by a dynamic combination of factors functioning at different levels. Companies might take advantage of developments at all levels and successfully market a new product, without necessarily being active in investments for a long period of time. However, the context matters. The context might refer to the type of application (i.e. more systemic or less systemic), or the degree of complexity of the technology (i.e. relatively simple or complex systems). Finally, caution is required as there is no panacea for the challenges faced by actors during the innovation phase. Solutions must be tailored to the specific context with which development and commercialization efforts are confronted.

Acknowledgements

This thesis is the result of a period of intensive learning that has contributed to both my academic and personal development. However, it could not have been completed without the inspiration, and support that I received from several people. Thus, at this point, I want to express my gratitude to them.

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List of Abbreviations

AIDC	Automatic Identification and Data Capturing
EAS	Electronic Article Surveillance
FFE	Fuzzy Front-End
H1	Hallmark 1
H2	Hallmark 2
IFF	Identification, Friend or Foe
IS	Innovation System(s)
NPD	New Product Development
OECD	Organization for Economic Co-operation and Development
PEM	Proton Exchange Membrane
R&D	Research and Development
RFID	Radio Frequency Identification
SNM	Strategic Niche Management
TI	Technological Innovation
TT	Technological Transition(s)
UHF	Ultra High Frequency
VoD	Valley of Death

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1.Introduction

1.1. Problem Context

The importance of technological innovation has increasingly become acknowledged for both organizations and society. From an organizational perspective, technological innovation is required for long-term survival and growth in competitive industries. According to the latest OECD innovation indicators, more than 10% of companies in several countries are engaged in product and/or process innovating activities[1] (OECD website). From a social perspective, innovation can contribute to economic growth, and increase the standard of living of groups in society (Solow, 1957; Ahlstrom, 2010). Moreover, innovative technologies have the potential to address environmental issues, such as renewable energy technologies for mitigating climate change and global warming. However, innovation remains a risky option for organizations. The road of many promising innovative technologies to the market is often long and rough, characterized by significant failure rates (Ernst, 2002). Innovative products have often been cancelled in the midst of their development, been late for their introduction to the market, or cancelled all-together shortly after their market introduction (Khurana & Rosenthal, 1997).

Pioneering radically new technological products, which are characterized by discontinuous improvement or the emergence of new markets, entails even higher risks for organizations, and more erratic patterns when it comes to the development and diffusion process (Tidd, 2010; Reid & De Brentani, 2004). An important aspect of the latter concerns the process through which the invention of a new principle is transformed into a product. The initiation of this process provides space for strategy formulation by those who seek the commercialization of the product (Ortt & Schoormans, 2004). The length of the period that spans from an invention of a technological principle to the first market introduction of a product based on that principle has been studied for several products and industries (Ortt, 2011). However, the existing literature lacks of a systematic analysis of its determinants. Thus, the research interest of this project concerns an exploratory investigation of the key actors and factors that affect the transformation of a radical technological principle into a marketable product. The ultimate aim is to identify barriers and facilitators to the first market introduction of a product incorporating a radically-new technological principle, and devise strategies for companies who aim commercialization.

1.2. Scientific and Managerial Relevance

From a scientific perspective, this project aims to explore how different actors and factors affect the innovation process of radically-new high-tech products. The scientific literature of innovation

[1]Note: excluding marketing or organizational innovations) and in some cases the innovative firms will also receive public backing.

management and new product development, will be examined and employed in order to propose a theoretical framework, which addresses the risks and the strategic options that emerge after the invention of a breakthrough technological principle, and before its initial market introduction. Subsequently, the framework will be illustrated and enlightened by the investigation of real-life case studies.

From a managerial perspective, the focus of this project is on providing useful insights on how to organize and manage innovation processes with an aim to better control the costs and risks. The postponed or unsuccessful market introduction of many breakthrough technological products indicates a need for organizations and entrepreneurs who pioneer products to better understand the erratic development and diffusion pattern of innovation. This project will enable managers of technology to have a clearer view of: (i) the nature of barriers and facilitators that emerge after the invention of a radical technological principle and before its first market introduction, and (ii) the appropriate strategies to deal with the aforementioned phase. The purpose is that the results can be useful as a tool for informed decision-making. Educated guesses, rather than intuition, can help achieve a higher success rate in innovation processes.

1.3. Scientific Background

The development and diffusion of innovation has attracted significant academic interest by diverse scientific disciplines (such as history, economics, sociology or management), and has been studied from different perspectives (such as the product, the R&D project, the R&D department, the company, the organization, the industry or the innovation system) (for a review see Nieto (2003) or Gopalakrishnan & Damanpour (1997)). Many researchers have tried conceptualizing the pattern of development and diffusion of technological innovations by proposing different models. The most popular representation of the large-scale diffusion of innovations is the S-shaped curve that shows the adoption of a product in the course of time (Rogers, 2003). More recently, Ortt and Shoormans (2004) suggested the extension of S-curve to capture the development and diffusion of breakthrough communication technologies. Their model, which is also depicted in Figure 1-1, included three subsequent phases: (i) the innovation phase (from the invention of a technological principle to the first market introduction as a product); (ii) the market adaptation (or niche) phase (from the first market introduction to the point that the diffusion takes off); and (iii) the market stabilization phase (from the diffusion take-off to the substitution of the technology). They also emphasized that each phase may vary in its length, and requires different strategies by the actors involved. Figure 1-2 shows the different possible scenarios that describe the pre-diffusion phases (Ortt, 2010). Additionally, Rogers (2003) stressed the need for more research focus on the period before diffusion. Knowing and explaining the characteristics of the pre-diffusion phases is of great interest for firms that want to commercialize breakthrough high-tech products.

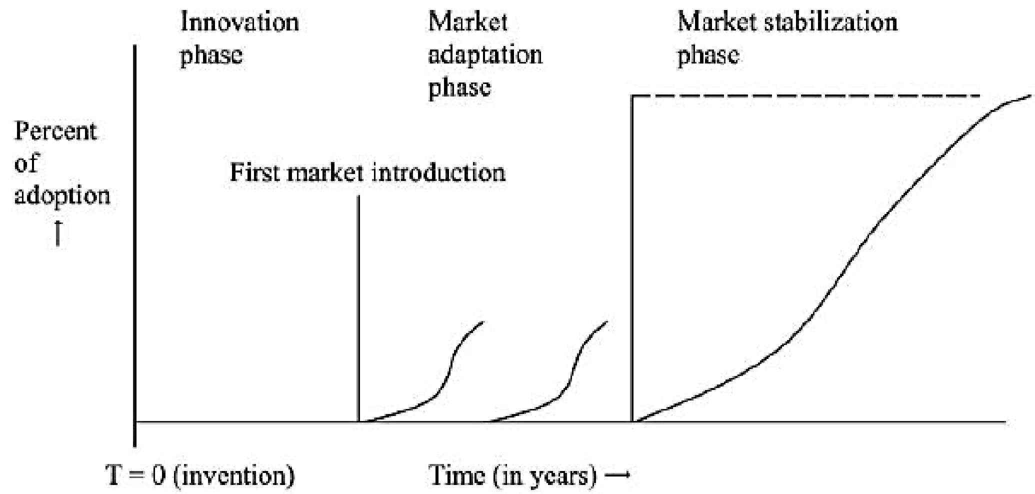

Figure 1-1 The pattern of development and diffusion of breakthrough technologies (Ortt & Schoormans, 2004)

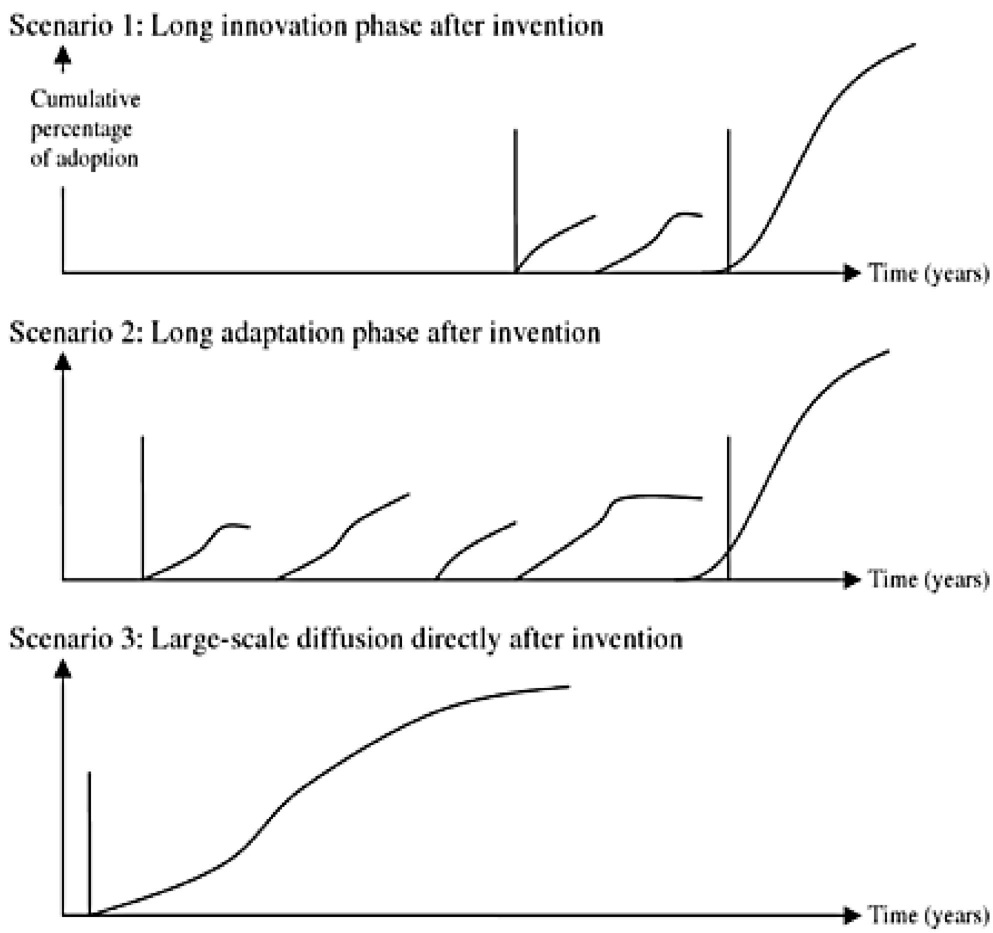

Figure 1-2 Different scenarios of the pre-diffusion phases (Ortt, 2010)

Researchers have also focused specifically on describing and explaining the length of the pre-diffusion phases. Ortt (2010) reviewed cases in which researchers estimate and interpret the period that intervenes after an invention and the first market introduction or the wider adoption of specific product categories. His study went a step further by comparing the length of the innovation and market adaptation phases for different products and industries, and recognized the erratic nature of the causes of pre-diffusion patterns. The findings suggest that the pre-diffusion phases last 16,7 years on average with a standard deviation of 14,5 years. More specifically the innovation and adaptation phases were found to amount to 10 years and 6,7 years respectively, with corresponding standard deviations of 13,5 years and 7,6 years. In the same study, categories of factors that affect the length of the pre-diffusion phases were identified, without however distinguishing between each pre-diffusion phase. The factors were related either to the market, the organization, or the technology. Still, it was acknowledged that further exploration regarding the strategies that organizations can adopt while they are in the pre-diffusion phases is needed.

Ortt et al. (2013) focused on what they called the adaptation phase, and identified different types of niche strategies to commercialize radical high-tech products. The strategies concerned types of niche applications (mostly by means of market niches) that can be employed when large-scale diffusion is blocked by specific factors. However, before the aforementioned period, the ability of organizations to develop quickly an invention of a breakthrough principle into the right radical high-tech product seems to have an increased importance for the success of the product (Cooper & Kleinschmidt, 1995; Murphy & Kumar, 1997). What respective barriers and strategies apply to the innovation phase?

Several theoretical fields relate to the innovation phase. From a macro perspective, the innovation phase can be seen as an early stage of Technological Transitions (TT), which are related to both social and technical change. In line with such a notion, the theory of Strategic Niche Management (SNM) relates the development of new technologies to the concepts of "experimentation" (p. 538) and "technological niche" (p. 538), which contribute to shifting to more sustainable regimes (Schot & Geels, 2008). Yet, such a view reflects many different products, projects, and organizations that are related to a group of technologies, and not the innovation phase of a product. On the contrary, other theoretical fields focus on more micro-level aspects of product innovation that relate to organizations and how they set up projects to develop new products. For example, theories that examine innovation within organizations discuss the role of the core capabilities of firms in the innovation process (Prahalad & Hamel, 2006; Leonard-Barton, 1992). On the other hand, theories belonging to New Product Development (NPD) mainly focuses on new product programs undertaken by firms. According to such a view, the innovation phase can be conceptualized as a step-wise (or stage-gate) processes that can improve the management of the NPD project (Cooper, 1990) (see Figure 1-3). However, other studies discussing the Fuzzy Front-End (FFE) of NPD, propose looking into the very early phase of the NPD process, which includes the period and activities that take place before an organization's first screening of a new product idea (Reid and De Brentani, 2004).

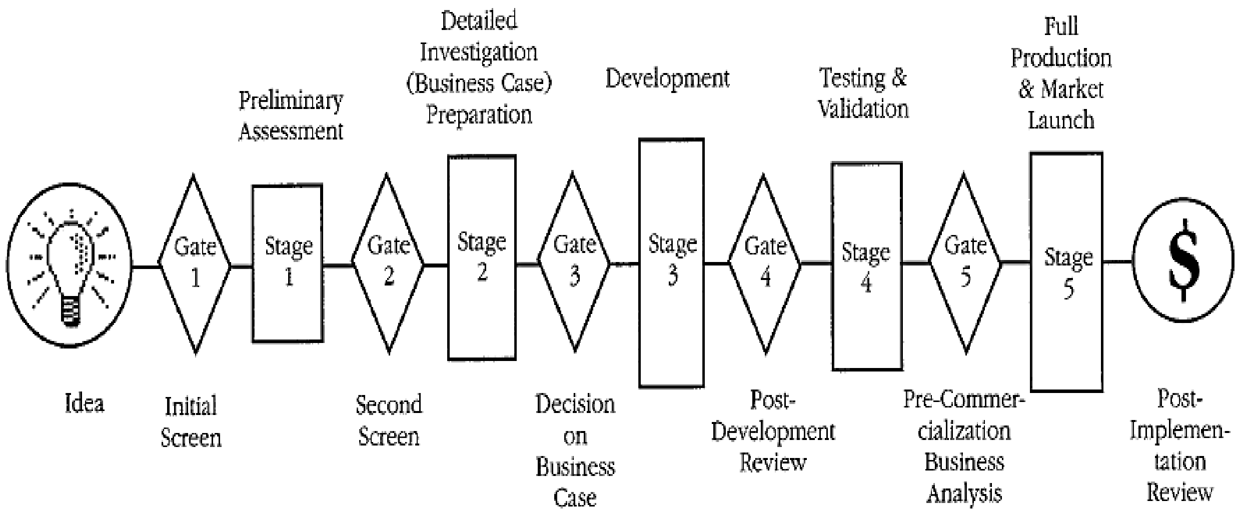

Figure 1-3 An overview of a stage-gate system (Cooper, 1990)

In agreement with the aforementioned observations, this study suggests that the innovation phase of products can be better understood if examined at different levels at which innovation takes place. As it will be shown, this paper confirms specific theoretical domains that relate to the innovation phase and combines them in order to present a more complete picture of the actors and factors that play a key role in the innovation phase. Note that although this study concerns the innovation phase of products, the aim is not to discuss the stages of the NPD process (e.g. such as those in Figure1-3), but to construct a higher-level representation of the innovation phase that allows many theories to be synthesized.

1.4. Research Objective

The objective of this research project is to contribute to the further development of the theories regarding innovation management, in particular with respect to the development and diffusion of breakthrough high-tech products. The focus will be placed on the exploration of the process of transforming the invention of a technological principle into a marketable product. This objective is achieved by providing insight, based on a literature study, into the way that different theories of innovation management can be synthesized to explain the phenomena. More specifically, the intention is to explore the nature of the key actors and factors that are involved in this process, as well as, their relationships. Only then, will organizations be able to earlier identify barriers, and devise suitable strategies. This will add further space for theory building in strategic innovation management and new product development, and call for empirical studies to test the theory developed and/or generalizing it beyond its context. In terms of practice, managers of technology can gain awareness of factors determining the successful development and commercialization of radical innovations.

1.5. Research Framework

In order to realize the research objective of the project, there is a need to specify the appropriate logical steps that were followed in the course of the project. This section proposes a research framework that presents a clear structure of the research plan. Figure 1-4 illustrates the proposed research framework, which shows that:

a) Theories related to the topic are reviewed in order to identify potential knowledge gaps and formulate an initial conceptual model;
b) Two historical case studies are examined with regards to the initial conceptual model;
c) The results of this process are cross-analyzed;
d) Conclusions are drawn based on the analysis

Note that this framework serves only the purpose of understanding the basic logical steps. A more detailed methodological framework is included in section 1.8.

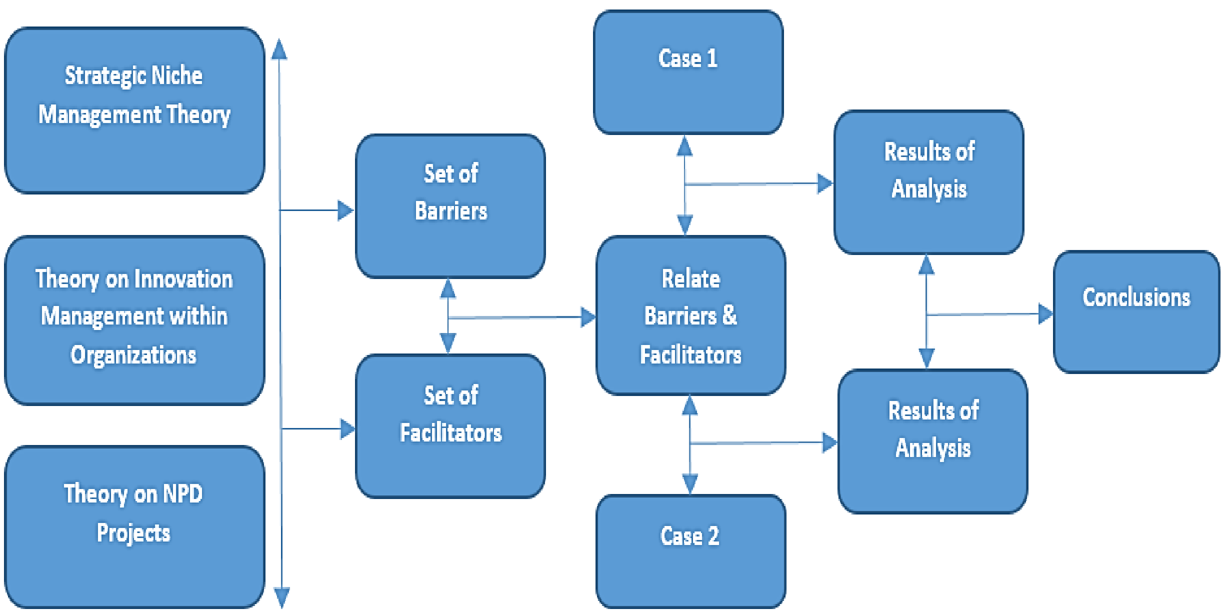

Figure 1-4 The research framework

1.6. Research Issues

After describing the logical steps that were followed in the course of the project, and reviewing the scientific background of the aim of this research, there is a need to specify the knowledge that is required in order to achieve the research objective. To deal with this, the main research question of this project has been formulated as follows:

“What barriers, facilitators, and strategies should be considered by an organization seeking the first market introduction of a radical high-tech product?”

In order to answer the main research question, the following sub-questions will be addressed:

1. *What are the key actors and factors that either hamper or facilitate the development of the invention of a new high-tech principle into a marketable radical high-tech product?*
2. *How are these barriers and facilitators interrelated?*
3. *What strategies can be proposed to organizations seeking to introduce a radical high-tech product for the first time into the market?*

1.7. Research Scope and Definition of Concepts

As previously explained, the main aim of this study is to explore the innovation process by means of the time period that spans from invention of a new principle (*hallmark 1*) to market introduction of a product based on that principle (*hallmark 2*). In order to explicitly define this phase, the following description has been adapted from Ortt and Schoormans (2004), which is also illustrated in Figure 1-5:

- *Invention* refers to the first demonstration of the principle (in a lab or an experimental situation) that is built up by the subsystems, and realizes the functionality.

- *Market Introduction* is the first introduction (either sales or implementation in practice) of a product version of the generic product.

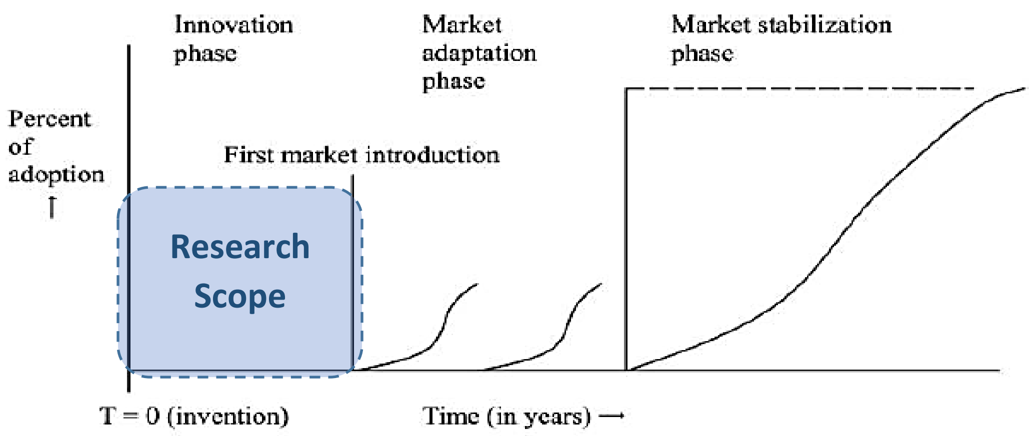

Figure 1-5 The scope of this project within the pattern of development and diffusion of breakthrough technologies as presented by the model of Ortt and Schoormans (2004)

With an aim to analyze the aforementioned phase of the innovation process, this project assumes that first market introduction is the overarching goal of the synergy among actors that are involved in the development of a new radical innovative product. Thus, actors and factors that function as barriers and/or facilitators, as well as, emergent strategies for organizations will be identified and described with respect to the aforementioned goal. Undoubtedly, this goal encompasses several sub-goals, which can also be perceived as prerequisites for market introduction. For example, Ortt et al. (2013) identified factors that act as necessary conditions for large scale diffusion of new high-tech products. Such factors mainly concern the availability of: a new high-tech product, complementary products and services, production systems, suppliers, customers, and rules and standards. However, this project acknowledges the existence of uncertainty with regard to how differently these elements behave when a product is introduced to an early niche market, where large scale diffusion does not necessarily occur. In addition, such behavior is expected to be case specific. For instance, for systemic technologies or platform products the availability of complementary products and services, or standards is expected to be more crucial for market introduction.

Note also that the scope of this project addresses technological innovation at the product-level. This should be emphasized because the invention of a new technological principle here involves a "rudimentary" version of a product that entails a specific functionality (e.g. a solar panel that is based on a new principle), and not a broad technological field (e.g. solar power) that might entail a group of technological products based on different functionalities. Similarly, the market introduction of a product concerns a concrete application of the product in a commercial environment (e.g. the first model of the panel that was sold to provide a specific function to an industry, a business, or and individual customer). Thus, whenever the discussion involves the invention, development, or market introduction of radical technologies, these technologies are understood as products.

1.8. Overview of Methodological Approach

In order to answer the research questions, the research design of this project incorporates three distinct phases (see Figure 1-6), and two different research methodologies: literature review (phase 1) and case studies (phase 3). The employment of both methodologies is expected to strengthen both the scientific and managerial relevance of this project. On the one hand, the literature review will further emphasize the scientific value of the research. Since little is known about the topic of this project, a literature research can reveal studies that relate to the topic, and position this study within existing literature. The aim of such literature research is to identify areas that are relatively under-researched, and to present a novel synthesis of existing work, which may result in a new way to look into the research problem at stake (Easterby-Smith et al., 2012). The existing knowledge gaps are addressed by the creation of a conceptual model (phase 2). On the other hand, empirical research will increase the managerial value of the research. The main reason behind the selection of case studies as the most suitable empirical approach for this research lies in the exploratory nature of this study (Yin, 2003). Specifically, the research involves unknown variables and relationships, thus calling for a rather inductive research approach. A detailed explanation of the specifics for the application of each methodology is provided in the corresponding chapters (i.e. chapters 2 and 4).

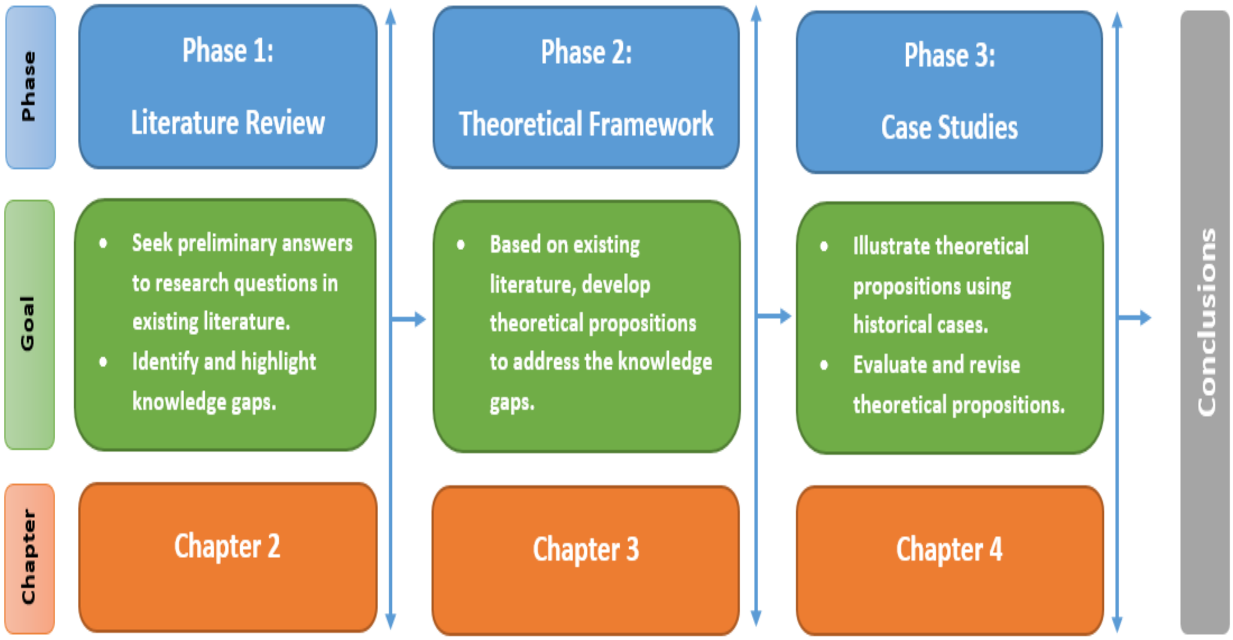

Figure 1-6 Research design

1.9. Structure of the Report

The structure of the remainder of the report is as follows. In chapter 2 I present a review of existing literature in order to describe what is known and what we need to know about the research topic. In chapter 3 I propose a theoretical framework in which findings from the literature are synthesized with a goal to provide further insight regarding the research problem. In chapter 4 I examine two historical cases of radical high-tech products to derive conclusions about the applicability of the propositions of the theoretical framework that was developed. Finally, in chapter 5 I discuss the overall conclusions, the limitations of the study, and provide suggestions for future research.

2.Literature Review

2.1. Introduction

In this chapter I will attempt to identify both the known and unknown factors regarding the research questions (see Figure 2-1 for the scope of this chapter). The central aim is to identify gaps in the relevant literature, and present a novel synthesis of existing work; this may result in a new way to look at the research problem. Undeniably, there is a vast body of literature that could be examined in order to identify the mechanisms that affect the transformation of an invention into a marketable radically innovative high-tech product. Various theories on innovation take different perspectives and focus on different aspects of the research issues that have been described in chapter 1. For the purpose of this project, specific scientific domains were considered, and studies have been selectively reviewed. What follows is a presentation of the methodology that has been applied, the results of the review, and the corresponding conclusions.

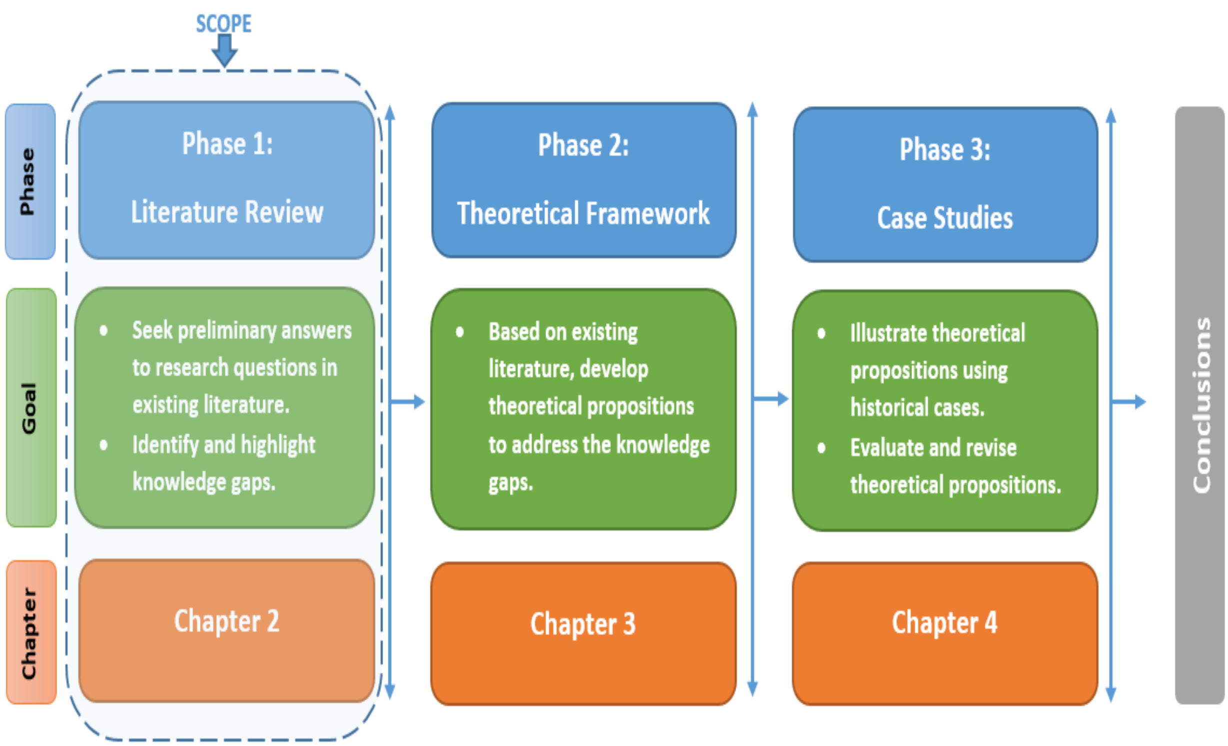

Figure 2-1 The scope of chapter 2 within the research approach

2.2. Methodology

2.2.1. Logic of Design

A literature review method that combines elements of both a theoretical review and a critical review has been employed in order to present a preliminary answer to the research questions. According to Paré et al. (2015), a theoretical review "draws on existing conceptual and empirical studies to provide a context for identifying, describing, and transforming into a higher order of theoretical structure and various concepts, constructs or relationships" (p. 188), while a critical review has the "ability to highlight problems, discrepancies or areas in which the existing knowledge about a topic is untrustworthy" (p. 189). In line with the aforementioned definitions, this chapter has two primary goals. The first goal is to examine how different innovation theories can be synthetized in order to provide a preliminary answer to the research problem. The second goal is to identify possible knowledge gaps regarding the research issues.

For the purpose of this project, in order to satisfy both theoretical and practical concerns, the technological innovation process is examined at different levels. From a theoretical point of view, innovation management studies follow various perspectives (e.g. social, economic, technological) and units of analysis (e.g. society, economy, industry, firm, R&D department, product) in order to understand related phenomena (Nieto (2003); Gopalakrishnan & Damanpour (1997)). From a practical point of view, the market environment within which different stakeholders interact, the characteristics of organizations that innovate, and the management of projects by organizations, have different effects on the development of new technologies. Consequently, this study distinguishes three levels at which factors facilitate or hamper innovation. The macro-level deals with the market environment, the meso-level with the organization, and the micro-level with the project. Thus, the problem in question concerns how the development of radically new technologies is regarded at each of these levels. More specifically, what factors facilitate or hamper technological innovation from invention to market introduction?

The reason for choosing the aforementioned approach is threefold. Firstly, the issue of successfully developing and commercializing product innovations pertains to a vast literature and several theoretical domains. However, an appropriate theory that addresses the research problem of this study is lacking. Secondly, in accordance with the exploratory nature of the study, by critically examining the way in which the different theories relate to the research problem, the emergence of knowledge gaps is expected to provide further focus and direction for the next research steps. Thirdly, due to the broad scope of the research questions of this study, an exhaustive search by means of all studies that relate to the issue is unmanageable. In other words, a systematic search for useful literature by applying key search terms to scientific databases is fruitless because it results in a very high number of hits, with however a very low percentage of articles that are actually relevant to the research problem. Nonetheless, the selected literature review approach that is employed here can be considered systematic and comprehensive to the extent that it covers the complete scope of this research. In particular, in their sum the different sub-literatures that were considered examine the development of new technologies from the perspective of: the market environment, the organization, and the project. Thus, the aim of this literature review is to combine diverse streams of research in order to examine their interrelationships and look for patterns that can assist the development of novel theories.

In order to further illustrate why the application of key search terms to scientific databases was not followed as a search strategy, the following example is provided: When it was attempted to use Scopus in order to find barriers and facilitators to innovation, as defined by the scope of this project, the string of keywords used was: “innovation” AND “barrier OR facilitator” AND “tech*”. Despite the fact that this search included only the abstract, title, and keywords of the articles of the database, it resulted in 3,602 relevant documents. However, such result can only be considered as “chaotic”, and it does not offer any particular value to the research since it would be impossible to review all these documents. Note also that these key words are relatively basic terms. If synonyms or more generic words are included in the search (e.g. factor or actor), then the results will further increase.

2.2.2. Search Strategy and Selection of Studies

Table 2-1 summarizes the sub-literatures and studies that are considered in this literature review. As the scope of this research distinguishes between market environment, organizational, and project-related factors, for each of these, a specific theoretical field was selected to be reviewed. The basic selection criterion was the relevancy to the research scope, i.e. the theoretical field had to focus on concepts that either enhance or hamper the innovation process as defined in the introductory chapter. The aim was to identify what actors and factors that act as barriers and/or facilitators are recognized by each theoretical field. The next step is to explore the relationships between these barriers and facilitators.

After the selection of the theoretical fields, a basic review of each field was executed so as to get familiar with its context. For each strand of theory, representative studies were selectively used as sources in order to answer the research questions. The choice of these studies was validated by an expert in innovation management theories (*Roland Ortt - Associate Professor Technology, Innovation & Entrepreneurship*). Table 2-2 illustrates the rationale behind the aforementioned selection process.

Table 2-1 Sub-literatures and studies that are reviewed in order to identify barriers and facilitators

Orientation towards the innovation process	Scope within which the development of new technologies is examined	Selected sub-literature for review	Selected studies to consist of the review	Description of each study
Macro Level: Market Environment	Socio-Technical Change	Strategic Niche Management	Kemp et al. (1998)	SNM: Regime shifts through niche formation
			Schot & Geels (2008)	Discussion of empirical findings and theoretical propositions in SNM
Meso Level: Organization	(Product) Innovation Management within Organizations	Organizational Capabilities/ Characteristics and Innovation	Leonard-Barton (1992)	Core rigidities and core capabilities in managing NPD: 20 case studies of product and process projects in five companies
			Trott (2011)	Organizational characteristics that facilitate innovation
		The Valley of Death in Innovation	Markham (2002)	The 'Valley of Death' in Product Innovation: Product Champions
			Markham et al. (2010)	The 'Valley of Death' in Product Innovation: Role Theory
Micro Level: Project	Success of NPD Projects	The Fuzzy Front-End of Innovation	Khurana & Rosenthal (1997)	Examination of 11 companies to improve the effectiveness of the front-end process
			Zhang & Doll (2001)	The FFE and Success of NPD: a causal model - Uncertainty theory

Table 2-2 Criteria for the selective search strategy

Criteria for Selection of Scientific Sub-fields to be Considered
• Does the theory relate to the innovation process? • Does the theory focus on challenges or ways to stimulate the innovation process? • Is the theory relevant for addressing mechanisms after invention and before market introduction?
Criteria for Selection of Studies as Sources
• Is the study dominant in the scientific sub-field? (i.e. Is it a key study that reflects well the sub-field?) • Does the study consider concepts relevant to the scope of this research? (i.e. Does the study consider barriers or facilitators or for the innovation process?)

As previously mentioned, the main reason behind the selection of these theories was that in their sum they assess a broad range of actors and factors from the perspective of the market environment, the organization, and the project. The relevance of each theoretical field or study is described as follows:

- **Strategic Niche Management**:

Kemp et al. (1998) introduced the SNM perspective as a response to the need for transitioning to more sustainable technological trajectories. The aim is to exploit the potential of promising technologies by bringing them closer to the market. The SNM approach assumes that barriers for the development and adoption of radical technologies, and especially systemic technologies, amount to a wide variety of factors concerning: the technology itself, the policy and regulation with respects to it, the demand for it, its production, the cultural and psychological characteristics of society, and the required infrastructure and maintenance to support it and its environmental consequences. The aforementioned factors are interrelated and reinforce each other. In response, SNM regards the creation, development, and management of niches (i.e. protected spaces that are useful for experimentation) as the most suitable way for the development of new technologies within an environment that is shielded from the larger market.

- **Organizational Capabilities and Innovation**:

The core capabilities (often called core or organizational competencies) of a firm seem to have an increased strategic importance for organizations that innovate (Prahalad & Hamel, 2006). Leonard-Barton (1992) adopts a knowledge based view of the organization to argue that firms face a paradox when managing NPD projects since the same core capabilities that can provide them with a competitive advantage may also hamper innovation.

- **Organizational Characteristics and Innovation**:

There exists a vast body of literature on specific determinants and moderators of organizational innovation (Damanpour, 1991). Trott (2011) describes some key organizational requirements that facilitate the innovation process. Although, the latter work comprises a handbook of innovation and not a theoretical paper, it is useful in order to derive a more practical description of capabilities of innovative organizations.

- **The Valley of Death in Innovation**:

Markham (2002) describes the Valley of Death as the lack of organizational resources, expertise, and structure between a technical invention that signifies a potential market opportunity and its commercialization. According to him, product champions, appropriate resources, and formal development processes are expected to help an organization cross the Valley of Death, thus bringing technologies closer to the market.

- **The Fuzzy Front-End of Innovation**:

The roots of failure for innovation projects can often be identified in their beginning. Studies suggest that performance during the front-end of the innovation process has a significant impact on the success of the whole process (Cooper, 1988; Murphy & Kumar, 1997). From a time-based operation perspective, the cycle-time of new product development is also influenced by performance during the early phases of the innovation process (Cooper, 1998,1999; Dwyer & Mellor, 1991). Efficiency in the front-end should be valued higher than efficiency during the design and manufacturing process, when firms seek to develop new products (Cooper & Kleinschmidt, 1995). Different models describing the front-end of innovation have been proposed by literature. A common understanding suggests that the front-end refers to the very early phase of the NPD process, which includes the period and activities that take place before the decision to develop a new product that requires investing in designing and manufacturing (Murphy & Kumar, 1997; Zhang & Doll, 2001). In one of the most popular models, Khurana and Rosenthal (1997) presented a stage-gate model in which the front-end consists of activities such as: idea generation, market and technology analysis, product definition, and project planning (see Figure 2-2). While a project leader or team often takes NPD decisions, the front-end activities often include strategic planning issues, which an organization has to face before the project is initiated.

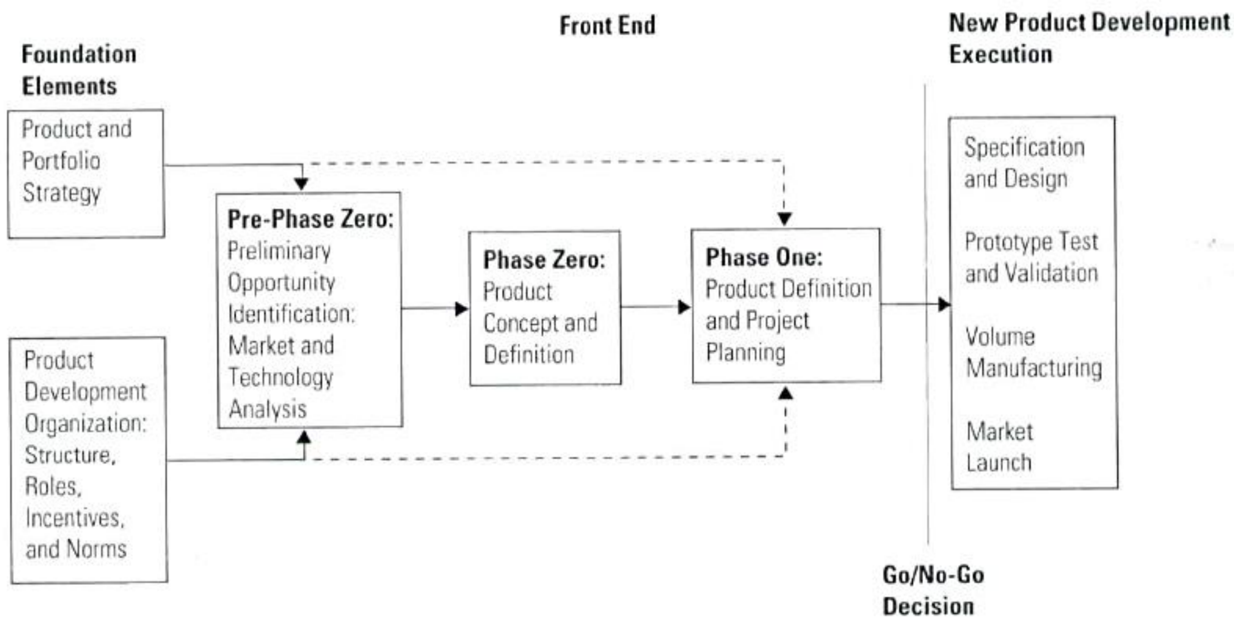

Figure 2-2 A model of the new product development front end (Khurana & Rosenthal, 1997)

2.2.3. Analysis and Synthesis Approach

Once the selection strategy was applied and the collection of relevant studies that was going to be used as sources was decided, a systematic process was implemented in order to analyze and synthesize the collected data. The aim the analysis and synthesis was: to understand and illustrate how the different parts and aspects of an individual study related to each other, as well as, to arrange information from different studies in a novel way, which could provide new insights to the research problem (Denyer & Tranfield, 2009). More specifically, this suggested: (i) identifying the most appropriate (f)actors that apply the time scope of the research problem (i.e. from invention to market); (ii) using categorizations of (f)actors that allow a macro-view of the issue; (iii) interpreting interrelationships among (f)actors.

In order to derive a list of actors and factors that affect either positively or negatively innovation, a step-wise process was followed. The purpose was to improve both the objectivity and the applicability of the findings. The initial step included reading the list of the selected articles and try to identify relevant actors and factors that either hamper or facilitate innovation. Once a preliminary list had been derived, in a second step, the articles were read again so as to secure that even actors that were not explicitly mentioned but directly implied, would be added to the list. The third step concerned examining for possible overlap between the actors and the factors, and merging synonymous terms. Finally, the fourth step comprised the categorization of actors and factors. The goal of this step was to produce a final list of actors and factors that were comparable in terms of the level of detail. In particular, the actors and factors were expressed in a way that would allow reflecting the basic building blocks of each of the studies.

2.3. Analysis

Strategic Niche Management Theory (Sources: Kemp et al. (1998); Schot & Geels (2008))

- **Key factors that affect the development of new technologies:**

The development of new technologies is influenced by the vision shared by communities of technological and economic actors. This vision takes the form of technological beliefs, approaches, and knowledge, as well as postulations about market needs. In turn, this shared vision constitutes an external selection environment for the development of new technologies that has to be taken into account by the organizations willing to innovate. The innovator organization forms its R&D and production efforts by anticipating such selection environment, which is influenced by all actors trying to promote specific technologies (such as suppliers, government, and users).

The development of radically new technologies might be hampered by beliefs that restrict the technological horizon of organizations. There is a range of factors that affect the evolution of a socio-technical system, and in turn the development of radically new technologies by organizations. The factors could be categorized into: technological, socio-cultural, macro-economic, legal or regulatory, environmental, and political factors. These factors are closely interconnected. In response, the formulation of clear expectations and visions is essential for the emergence of technological niches since it serves as a basis for guiding learning mechanisms with regard to the aforementioned range of factors. Furthermore, it is expected to facilitate the promotion, the protection, and the nurturing of a new technology. The latter elements are considered central for the successful development of a technological niche.

Another critical element for the development of new technologies is the formation of social networks. Such process can enhance the interaction of an organization with other stakeholders. In addition, organizations can take advantage of this process to acquire financial, human or social capital that is regarded as necessary for the development and commercialization of the new technology.

- **Key actors that affect the development of new technologies:**

Public policy makers are regarded as the most important actor that affects the development of new technologies, since they impose social goals, which act as drivers of socio-technical change. Public policy makers may employ three different types of strategies in order to promote new socio-technical systems: by altering the market incentives (e.g. imposing taxes on negative externalities), by designing the development of new socio-technical regimes (e.g. by promoting large infrastructure projects), or by creating “protected spaces for the development and use of promising technologies by means of experimentation” (p.186) (e.g. by organizing series of experiments with certain technologies). The latter is what is referred to as the Strategic Niche Management process.

Although Kemp et al. (1998) focus primarily on the role that governments can play; they propose that all actors that seek to push a new technology to the market can potentially act as niche managers. Schot and

Geels (2008), emphasize further the notion that niches are not created by governments in top-down fashion, but rather they evolve as a result of an internal steering (Rip, 2006), which can be realized by various actors such as users or societal groups.

The Valley of Death in Innovation (source: Markham (2002); Markham et al. (2010)

- **Key factors that affect the development of new technologies:**

The lack of resources, activities, and formal roles is the major factor that is expected to hamper the process of moving new technologies from an R&D lab to commercialization efforts. Specifically, organizations face a gap in appropriate funding, and structure after a discovery and before the initiation of a NPD project. As a response, in order for an organization to cross what is referred as the Valley of Death, product champions, critical resources, and formal development processes are required.

- **Key actors that affect the development of new technologies:**

The most important actor in crossing the Valley of Death is the product champion. Champions are informal leaders that emerge in unpredictable ways within organizations. They are regarded as responsible for promoting specific projects by influencing the expectations of other members in an organization. The major activities with which they are engaged involve: securing critical resources by presenting a vision, demonstrating the potential of a product concept by preparing a business case, and achieving the decision of an organization to proceed to a formal development process.

Organizational Capabilities and Innovation (source: Leonard-Barton (1992))

- **Key factors that affect the development of new technologies:**

The core capabilities of an organization can simultaneously boost and hamper the development of new technologies. While the distinctive capabilities of organization signify a strategic advantage for it, they may also be destroyed by technological discontinuities within an industry. Innovation suggests creative destruction, which suggests that core capabilities of organizations evolve constantly. From a knowledge based view of an organization, core capabilities are characterized by four major dimensions: (1) skills and knowledge base; (2) technical systems; (3) managerial systems; and (4) values and norms. Values pertain all dimensions of the knowledge set of an organization, additionally; all dimensions interrelate with each other to form a core capability. For each of the four dimensions that comprise a core organizational capability, specific factors are expected to enhance or impede development. For example, when considering the skills/knowledge dimension, factors like excellence in the dominant discipline and pervasive technical literacy are expected to enable development, while less expertise in non-dominant disciplines will likely inhibit development. When managing NPD projects organizations might have a hard time deciding whether to build on existing core competencies or build new ones. The interplay between NPD projects and capabilities might last months or years.

- **Key actors that affect the development of new technologies:**

Project managers will have to deal effectively with the tensions that result from the symbiosis of the core capabilities of an organization with an NPD project. The misalignment between projects and core capabilities is usually handled by project managers in four basic practices: (1) abandonment of the project; (2) return to core capabilities; (3) reorientation (e.g. by assigning the project to another division); and (4) isolation by cutting off physically and psychologically the project from the rest of the firm.

Project managers should consider multiple frameworks as part of a self-renewing organization. By challenging traditional systems, skills, and values in a constructive way they can enhance a continuous organizational renewal that is necessary for technology-based organizations. Such renewal entails redefining existing competencies or initiating new ones.

Organizational characteristics and Innovation (source: Trott (2011))

- **Key factors that affect the development of new technologies:**

The following organizational characteristics are expected to act as important facilitators for the development of innovative products:

- ✓ Growth orientation: Firms that seek growth are the ones most likely to innovate.
- ✓ Vigilance: Formal and continuous external scanning processes are likely to bring to the organization all the valuable information.
- ✓ Commitment to technology: A company must be willing to invest long-term in the development of technology in order to attract good scientists and enhance creativity for the quick identification of the most promising ideas.
- ✓ Acceptance of risks: Innovative firms manage balanced portfolios of projects in terms of risks.
- ✓ Cross-functional cooperation: Successful innovation requires dealing efficiently with the conflicts among different departments.
- ✓ Receptivity: Firms must be able to identify and exploit opportunities by means of externally developed technologies.
- ✓ Slack: Allowing scientists to work on their own projects will likely increase creativity that fosters innovation.
- ✓ Adaptability: Radical innovations may require altering existing organizational routines.
- ✓ Diverse range of skills: The co-existence of a mixture of specialists and individuals with hybrid skills facilitates the knowledge transfer within organizations.

- **Key actors that affect the development of new technologies:**

Specific actors are not mentioned.

The Fuzzy Front-End of Innovation (sources: Zhang & Doll (2001); Khurana & Rosenthal (1997)

- **Key factors that affect the development of new technologies:**

Understanding the pre-development phase of innovation plays an important role in the successful commercialization of innovative products. However, the nature of the decisions and activities that take place during this phase are characterized by increased complexity and uncertainty. Scholars that discuss the 'fuzziness' in the front-end of new product development, emphasize its dynamic and unstructured nature (Murphy & Kumar, 1997). The major challenges of the front-end are uncertainty and interdependencies. Zhang and Doll (2001), describe the "fuzziness" in the front-end as environmental uncertainty "related to market changes, emerging technological developments, and the evolving competitive situation" (p. 95). Such environmental fuzziness is expected to have a negative effect on a project's team vision, by means of: shared team purpose; strategic fit of project targets; and clarity of project targets.

Failure during the FFE can result in products being called-off in the midst of their development or late market introduction, mainly because of strategic misalignment and product concept issues (Khurana &Rosenthal, 1997). According to this point of view, what hampers quick and successful development of innovations, is the poor execution of a set of interrelated activities that can be project-specific (such as product definition, and product concept) or cut across projects (such as strategic vision formulation and communication, product portfolio planning, and product development organizational structure). The solution can be a well-engineered cross-functional process in which best practices are followed to remove the unnecessary fuzziness from the front-end. However, while it is acknowledged that different front-end approaches should be employed depending on the firm's product, market, and organizational contexts, there is no reference to specific front-end strategies depending on the challenges faced.

- **Key actors that affect the development of new technologies:**

The core project team is responsible for reducing the uncertainty that prevails in the FFE of NPD projects (Zhang & Doll, 2001). The cross-functional NPD team is expected to perform the key activities that are required for integrating the FFE of the NPD project. Teams should not only collect information but also communicate it successfully to all members, as well as incorporating them in the design phase of an NPD project. The cross-functional front-end team, is required: to establish a clear shared vision that is built on shared knowledge, and will have a positive effect on the success of NPD; to conclude in project priorities based on the product strategy and resource availability, which in turn depends on customer, technology, and competition-related information; to come up with an explicit product definition and project planning.

2.4. Results

Table 2-3 presents the combined results of the literature review, with regard to the identification of factors. The factors are generic, and should be viewed as categories of more specific factors. They represented basic building blocks of the theories that were examined. This served the purpose of presenting a rather complete picture of the types of factors could be found at each level. However, I cannot claim that the list of factors is exhaustive. Possible examples or forms of the factors are also presented in order to provide the reader with a clearer understanding of how these factors could function.

Table 2-3 Factors at multiple levels

Factor	Function/Examples
Macro-Level	
Technological Factors	Unless technologies are well- developed in terms of users' needs and by means of the function they provide, actors might not be interested in their commercialization.
Economic Factors	The cost related to the development and use of the technologies might significantly affect both the supply and demand sides.
Supply & Production Networks	Natural resources or complementary products might be required for the development or commercialization of new technologies.
Infrastructure & Maintenance Networks	The development of a suitable infrastructure, which can involve many actors, might be necessary for the application of a new technology.
Social Networks	Social relationships among different stakeholders are important for resource mobilization (e.g. financial resources, human resources, and other types of capital) that enhance development.
Psychological & Cultural Factors	The cultural meaning of a new technology should take into account existing social norms and values, which characterize prospective users. Otherwise, market actors might not be interested in commercialization.
Social & Environmental Effects	Environmental friendliness determines the social desirability of the technology, and in turn the promotion of certain technologies.
Government Policy	Technology policies should be clear enough to guide planning and production efforts by all actors.
Legislation & Regulation (Laws, Standards and Rules)	Laws, standards and rules may either stimulate or hamper the development of a new technology.
Meso-Level	
Scientific Knowledge & Firm-Specific Techniques	Both scientific knowledge embodied in employees (e.g. excellence in dominant discipline or a diverse range of skills) and firm-specific techniques might be important for the development of a new technology within an organization.
Technical Systems	Firm-specific technical systems such as information systems or simulation techniques may help develop a new technology.
Managerial Systems	Many aspects of managerial systems might affect the innovation process: Allowing scientists to spend time on their own projects is desirable for innovativeness; The ability to identify and exploit opportunities by means of externally developed technologies might enhance development; Formal and

	continuous external scanning processes are likely to bring to the organization all the valuable information; Cross functional cooperation should resolve conflicts between departments with different interests.
Organizational Culture & Values	Commitment to technology and willingness to invest long-term might be critical to attract good scientists. Acceptance of risk and adaptability (e.g. for altering organizational routines) are also desirable for innovating.
Financial Resources	Considerable financial resources might be required for developing new technologies.
Micro-Level	
Opportunity	The development of a new product is based on an opportunity worth exploring.
Product Concept & Definition	A detailed product concept facilitates new product development. Similarly, a complete and stable product definition facilitates new product development.
Project Planning	An explicit and thorough project planning facilitates new product development.
NPD process	A formal NPD process that concerns aspects such as manufacturing and testing the product is necessary for market introduction.

Similarly, Table 2-4 presents the actors that were found to be relevant to each of the levels distinguished. Note that the actors in some cases appear as entities, whereas in other cases they are determined by their role within the context of the innovation process. As in the case of the factors, by presenting these actors I do not claim completeness by means of an exhaustive list. Moreover, not all of these actors are explicitly listed in the articles that have been examined, but according the studies reviewed they are the most likely to play a role in the innovation phase of radically new high-tech products.

Table 2-4 Actors at multiple levels

Level	**Relevant Actors**
Macro-Level	Governments; Research Institutes; Universities; Industries; Policy-makers; Regulators; Suppliers; Providers of complementary products; Potential Users (Early Adopters)
Meso-level	(Network of) Companies-Developers; Top-management; Executives
Micro-level	Product Champions; Project Managers; Project Teams

2.5. Conclusion

Three different theoretical perspectives (i.e. the market-environment; the organization; and the project) were examined in order to provide a comprehensive picture of the actors and factors that either facilitate or hamper the development of new technologies. A literature review covered these perspectives by selectively looking into different sub-fields of scientific literature. After reviewing the main articles from each sub-field, the primary conclusion to be drawn was that the sub-fields do not build on each other in order to combine the different information they present. This lack of integration suggests a considerable knowledge gap. In order to accomplish a more complete view of the innovation process, as defined by the scope of this paper, it is necessary to explore the existence of relationships between the different barriers and facilitators that are identified by the different sub-fields of literature.

3.Conceptual Framework

3.1. Introduction

In chapter 2 I argued that in order to systematically identify barriers and facilitators of the innovation process from invention to market introduction, it is necessary to take into account different perspectives of the innovation process. Thus, I have reviewed key theories that examine product innovation by taking as a starting point: the market environment within which transitions to new technological regimes take place; the organization that seeks growth or survival by considering the commercialization of radically new technologies; and the project within which a new product is developed in order to be introduced to the market. The literature review revealed that each of the theories claims different types of barriers and facilitators with respect to the development of radically new technologies. However, little is known about patterns of interaction among the identified barriers and facilitators.

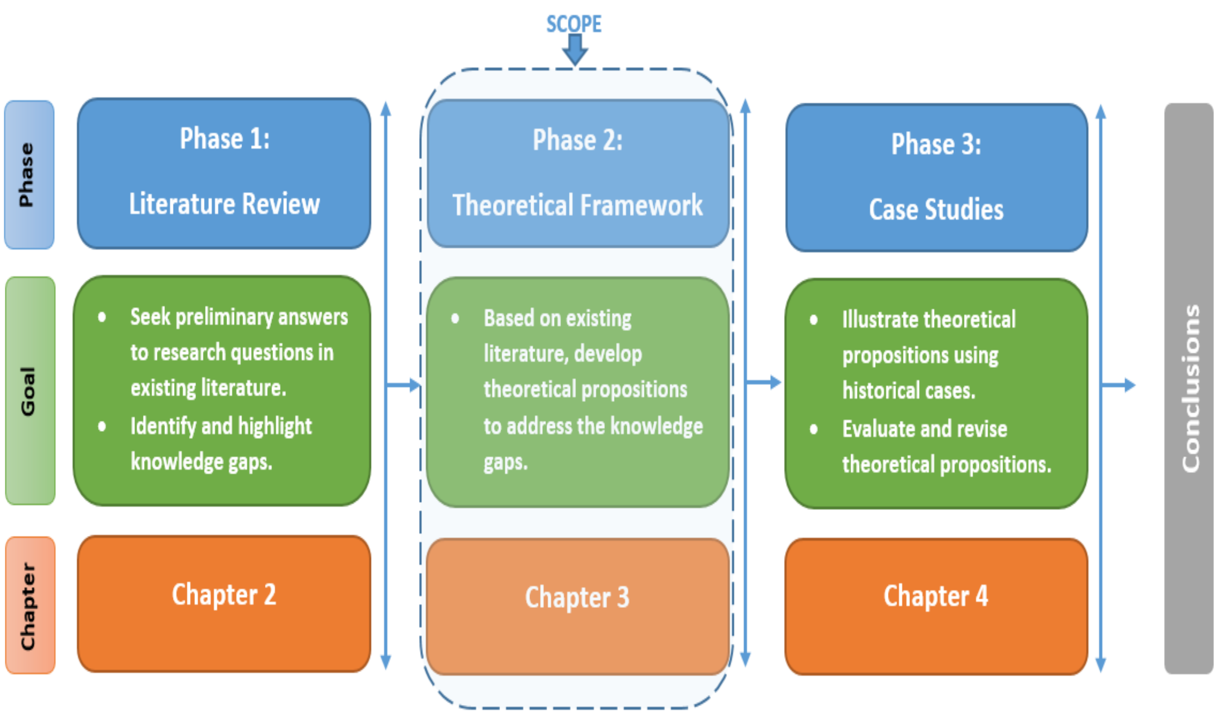

Figure 3-1 The scope of chapter 3 within the research approach

The position adopted in this chapter is that a multi-level approach can help to better understand the development of radically new technological products (see Figure 3-1 for the scope of this chapter). This type of approach addresses interactions among barriers and/or facilitators both within and across levels at which the innovation process is taking place. The rest of the chapter elaborates the latter notion, by proposing a theoretical framework that can be useful to map the landscape in which innovative organizations operate.

3.2. Multi-level Approaches in Innovation Studies

The idea of a multi-level approach regarding the development and diffusion of radical technologies is not new for innovation studies. Geels (2002), for example, argued that technological transitions (i.e. major technological transformations in the way societal functions are fulfilled) come about as a result of linkages between developments at different levels. His model includes: a macro-layer that consists of a slowly evolving socio-technical landscape that contains economic, cultural, political, and other types of factors; a meso-layer that consists of patchworks of socio-technical regimes, which can be viewed as stable systems consisting of multiple networks of actors such as producers, suppliers, users, authorities, and others; and a micro-layer in which radical innovations evolve in technological niches, some of which will also fail to enter the regimes. His seminal article suggests that radical innovations are expected to enter socio-technical configurations when linkages at the regime level become more unstable.

Other studies have also considered multi-level approaches in order to discuss innovation management practices. Ortt and Smits (2006), discussed progress in innovation management as a multi-level endeavor, by recognizing trends within three distinct levels in the innovation system. In their conceptualization the micro-level represents an organization, the meso-level an industry, and the macro-level a country. Although specific trends within each of these levels have different effects on the innovation management, it was acknowledged that combining the trends can provide further insights to consequences for the innovation process. In another study, Ortt and van der Duin (2008) identified four types of contextual factors of innovation activities in order to argue for the evolution of innovation management. These categories of factors, which can also be interpreted as levels, were related to the type of: innovation, organization, industry, and country (or culture). The aforementioned examples illustrate the multidimensional nature of the innovation process, which often requires considering constructs and notions at different levels when a phenomenon is examined from a rather broad scope.

In this paper I focus on how the development of radically new technologies should be regarded by organizations. As previously explained, here the aim is to shed light onto the period that begins with the invention of a radically new technological principle and ends with the first market introduction of a new product incorporating the principle. In order to understand the landscape within which the innovative organization operates, it is essential to focus on the functions of several barriers and facilitators to market introduction. To achieve this, the project theorizes that an organization needs to consider actors and factors along three broad and separate but interrelated levels: the market environment, the organization, and the project (see Figure 3-2). As chapter 2 showed, key theories have proposed different barriers and facilitators at each of these levels. However, by examining barriers and/or facilitators individually only at one of these levels, or treating these levels separately, organizations will likely have a limited view on what occurs after the invention of a new technological principle, and thus make biased decisions. Therefore, I propose that the concepts that are suggested by different theories should be synthesized following the construction of a multi-level approach to the matter.

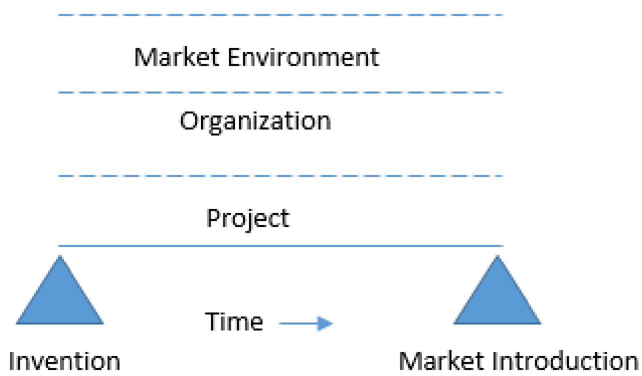

Figure 3-2 Three levels to examine the development of radically new technologies

In order to illustrate the value added by a multi-level approach, I will briefly employ the following historical example of the development of stationary PEM fuel cells in the US innovation system by Nail et al. (2003). If an organization wanted to explain what factors impeded the quick development of the stationary PEM fuel cells in the 1970s and 1980s, it would probably have recognized two types of barriers at the market environment level: unfavorable policy, as the US government had chosen to subsidize competitive fuel-cell technologies; and lack of demand caused by the very high cost of the materials required for the technology. These factors were interrelated, since the progress of competitive technologies would also lead to reduced demand by potential users of PEM fuel cells. At the organizational level, organizations developing at the time PEM fuel cells faced the challenge of limited resources. At the project level, these factors would most likely cause uncertainty with regards to the kind of products that were developed by competitors, and the kind of materials that should be used in the technology. In turn, such fuzziness could have a negative effect on the success of the NPD project.

However, at the organizational level, the vigilance of the two organizations helped to achieve important breakthroughs in the performance of the technology. In particular, the people of Los Alamos National Laboratory convinced the Canadian company Ballard Research that the cost of materials required could be reduced, thereby making PEM fuel cell a more economically viable solution. Thus the two organizations worked in parallel and collaborated to stimulate the development of the technology. Another, form of vigilance can be identified in the fact that Ballard exploited the recently expired Patents of General Electric. It is also noteworthy, that the Ballard's project team admitted that shortening the budget did not hinder, but rather, helped the success of their work as it resulted in a simpler design of the technology. This example shows that breakthroughs in the development of radical technologies are often the result of factors occurring at different levels, which reinforce, rather than compete, with one another. Thus, delays in the market introduction of radical technologies by organizations are more likely to be understood by such mechanisms and patterns, rather than explaining barriers and facilitators to developments at a single level.

3.3. Factors at Different Levels

In line with the previous analysis, Figure 3-3 shows a static list of factors that act as either barriers or facilitators at the three levels that are distinguished in this paper. These factors were identified in key theories that claim appropriate concepts when discussing ways to facilitate the innovation process (see chapter 2). These elements are hereby identified in order to highlight major mechanisms that either block or enhance the transformation of the invention of a new technological principle into a marketable product.

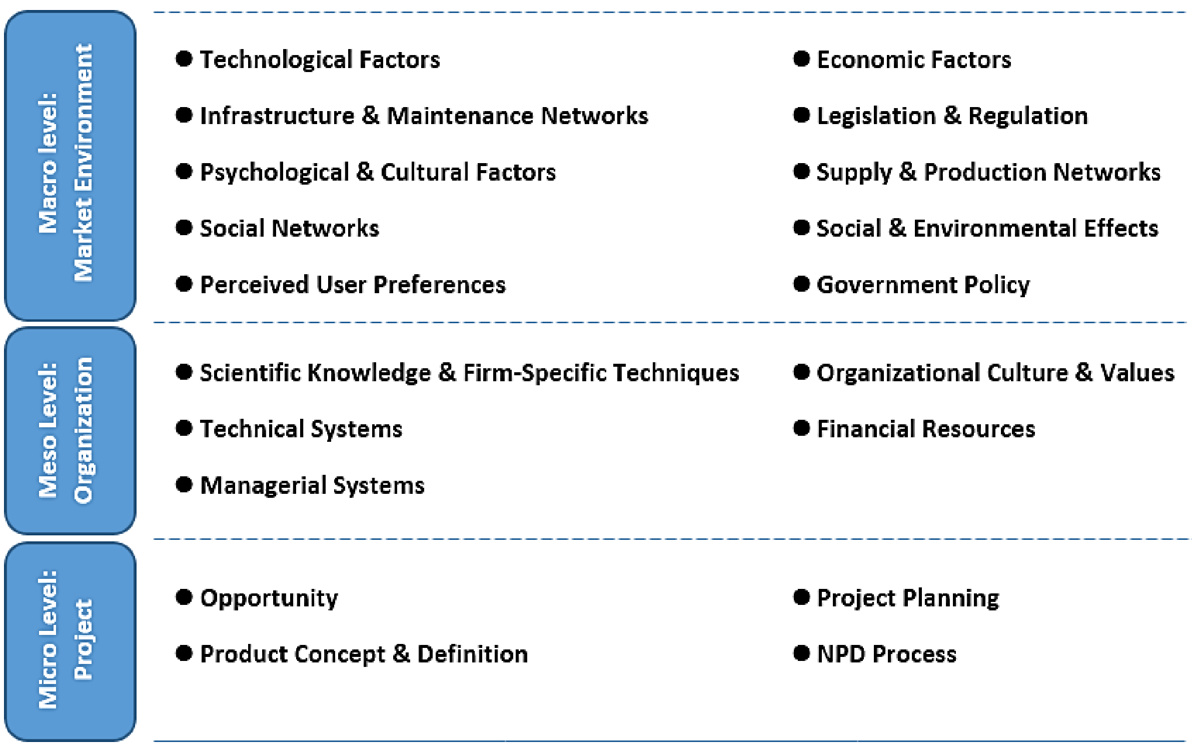

Figure 3-3 Factors (barriers or facilitators) at multiple levels

3.4. Interaction among Factors

Although barriers and facilitators occur at different levels, some of them can spread through all levels. For example, the governmental policy might guide the selection of specific projects by organizations. The description of the barriers and facilitators (see chapter 2) also reveals patterns of interactions among them. Several mechanisms that affect either positively or negatively the commercialization of technologies can be distinguished. Some simple mechanisms include the following:

- **Mechanism 1** - Facilitators diminish barriers within the same level: E.g. acquiring funding from venture capital can fill the lack of resources after discovery and before commercialization, thus bringing an invention closer to the market.

- **Mechanism 2** - Barriers reinforce other barriers within the same level: E.g. environmental uncertainty about the quality of raw material causes a lack of clear team vision, thus reducing the chance of NPD success.
- **Mechanism 3** - Barriers at one level may reinforce barriers at another level: E.g. a lack of resources after discovery will hinder the creation of a clear team vision since there will be not a formal communication system, thus reducing the chances of a successful NPD process.

Yet, a more careful look at the factors allows identifying more advanced mechanisms such as the following:

- **Mechanism 4** - Facilitators may diminish barriers at different levels simultaneously: E.g. vigilance may result in the adoption of complementary technologies that were not apparent initially, and thus also reduce the uncertainty with regards to the performance of a new product (i.e. a technological factor). As a result, the market potential of a newly invented technology might become more visible (i.e. a new market opportunity).
- **Mechanism 5** - A combination of facilitators maybe required in order to diminish some barriers: E.g. a product champion is expected to promote his vision of a new promising project to different stakeholders within a company, but at the same time cross-functional cooperation is required in order to develop a clear team vision that will result in developing the right product.
- **Mechanism 6** – A chain of reinforcing barriers might create a negative feedback loop: E.g. a lack of clear policy plans by the government, will likely result in a lack of resources for further R&D since an organization will not risk producing a part of a technological system for which there is no expectation also expressed by public policy makers. However, this might inhibit the project planning process, and an organization might also consider to stop promoting a particular radical technology. In turn, this will hamper the creation of network(s) of actors at the market environment level.

Figure 3-4 illustrates a scene that can potentially be formed after taking into account all of the aforementioned mechanisms. Barriers and facilitators are visualized as rectangles in order to reflect the fact that they have a time dimension. For the sake of simplicity, this illustration depicts barriers and facilitators with the same time-length. This is also because their time dimension has not been discussed in the previous examples of mechanisms. However, as the case studies of the next chapter will show, a historical perspective reveals that factors may significantly vary in their duration. Note that such visualization does not consider the time-sequence to barriers and facilitators. This is to say, barriers, facilitators, and interactions are placed irrespective of their sequence by means of time.

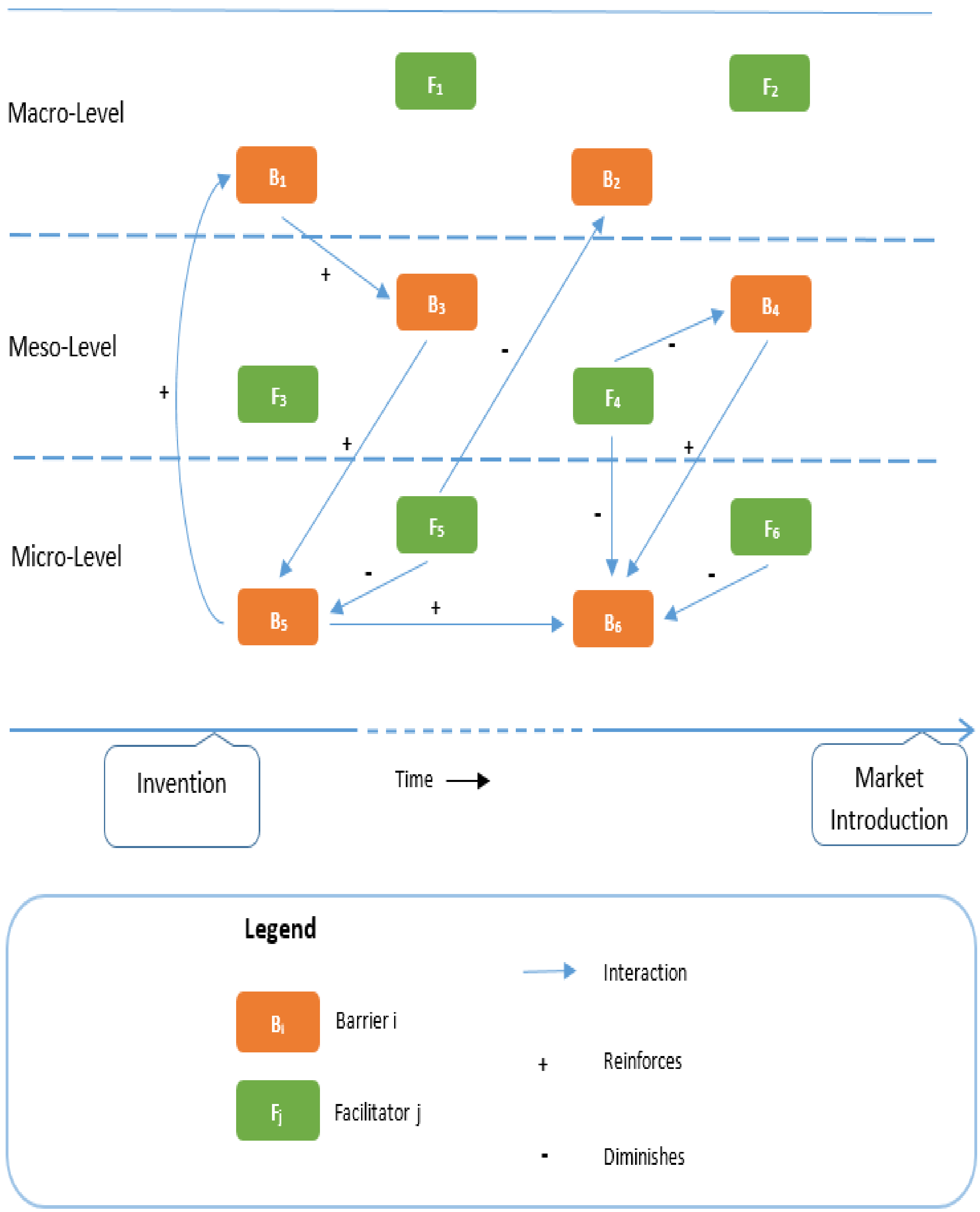

Figure 3-4 Interaction among barriers and facilitators within and across levels

These notions have two important implications: Firstly, the aforementioned interrelationships reveal a web consisting of barriers and facilitators that may have multiple causes and effects at the same time. This in turn suggests a rather complex landscape for organizations, where the emergence, the withdrawal, or the evolution of a barrier or a facilitator may signify a "game changer" for the commercialization of the new technology. Secondly, the existence of a barrier may lead to a negative feedback loop that blocks radical innovation. The latter process is revealed by Mechanism 5 in which barriers reinforce each other.

3.5. Conclusion

This chapter proposed a multi-level approach in order to explain how barriers and facilitators function after invention and towards the market introduction of a radically new technology. The framework allows organizations to not only be able to identify elements at all levels, but to also understand the dynamics that result from the interaction among the elements. Several types of mechanisms that either block or enhance the innovation process were identified. Although, such conceptualization suggests a rather complex landscape for organizations seeking to commercialize new technologies, it aims to assist the process of devising more holistic business strategies.

4. Historical Case Studies

4.1. Introduction

In the last chapter I showed that barriers and facilitators to the commercialization of radically new technologies should be regarded by a multi-level approach in which factors interact with each other. This chapter builds on this notion with an empirical inquiry based on the development of the aforementioned propositions, which are used to guide data collection and analysis (see Figure 4-1 for the scope of this chapter). In particular, two historical cases of radical Automatic Identification and Data Capture (AIDC) technologies that have become commercially available over the past decades are examined for both exploratory and descriptive purposes. The two cases that are analyzed are the RFID (Radio Frequency Identification) and barcode technologies. The aim of the case studies is twofold: firstly, to determine what factors are visible in the cases, and secondly, to identify interactions among factors both within and across levels. Hereby, not only will specific examples of the notions of the conceptual framework (see chapter 3) be illustrated, but the need for potential adaptations might also be revealed. The rest of the chapter proceeds with exemplifying all relevant methodological aspects and presenting both an in depth analysis and comparison of the two cases based on which conclusions are drawn.

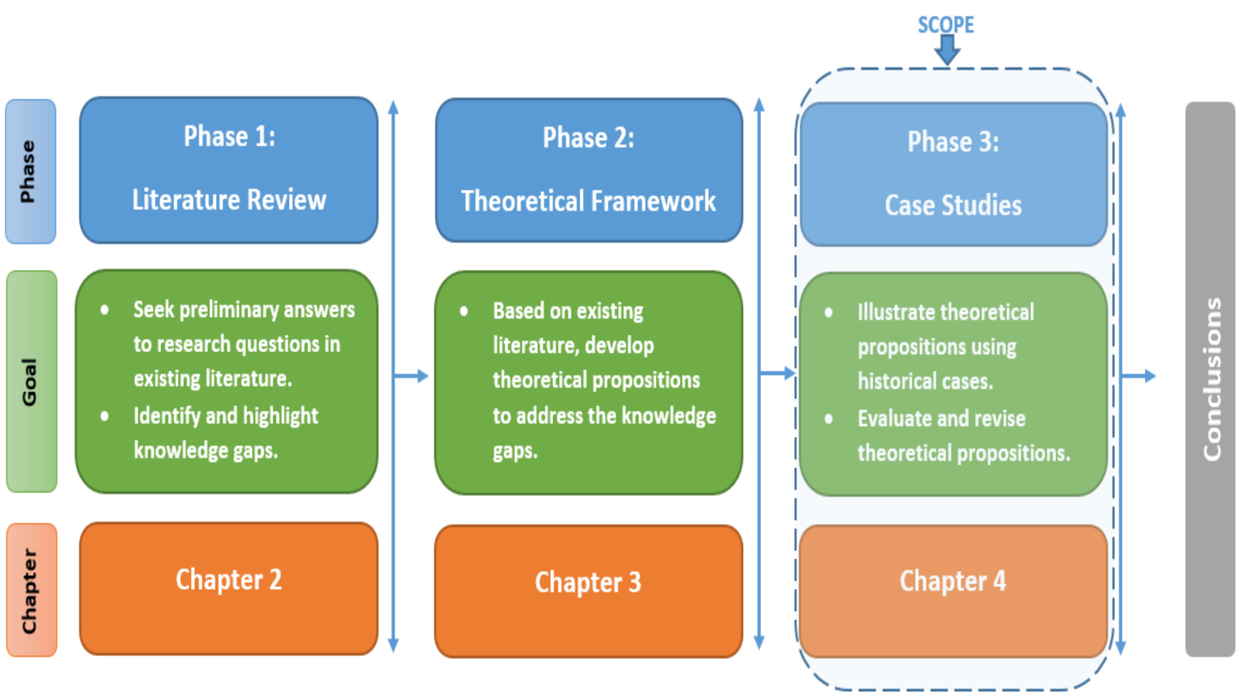

Figure 4-1 The scope of chapter 4 within the research approach

4.2. Methodology

4.2.1. Logic of Design

A historical analysis of cases was chosen as the most suitable empirical approach for this project. This method can be seen as a combination of case studies and historical analysis. Historical analysis is the practice of critically examining and summarizing a combination of past events based on relevant records and accounts (Marshall & Rossman, 2014), while case studies focus on investigating specific phenomena within their real-life context (Yin, 2003). Although case studies deal with contemporary phenomena, the study of history offers the advantage of reviewing the chronological aspect of past situations when compared to interviews or surveys. Here, the cases regard radical technologies that have become commercially mainstream over the last decades.

The work of Yin (2003) offers explicit reasons for which a multiple-case study design was an advisable approach for this research project. To begin with, case studies are suitable for exploratory purposes. What is more, a multi-case study is preferred over a single-case study, as it increases the robustness of the results. Finally, it is worth mentioning that before deciding on the number of cases, it was acknowledged that it would be impossible to examine in depth a broad heterogeneous sample of technologies because of resource and time constraints. Yet, by analyzing two cases, the results will likely become more plausible since a second case can add further insights to the issues of interest.

4.2.2. Unit of Analysis

The unit of analysis was narrowly determined by the description of a generic high-tech product as given in Ortt et al., (2013): "The product can be defined and distinguished using three elements: the functionality provided by the product, the technological principle(s) used and the main components in the system (first tier of subsystems)" (p. 4). The generic high-tech product also had to be radically new, by means that it had achieved a remarkable advancement of price/performance ratios or it allowed changes in the behavior pattern of adopters (Ortt et al., 2007). The radically high-tech product was developed by an organization or a network of organizations.

4.2.3. Case Selection

Three main criteria were employed in order to choose which cases to investigate. The first criterion was related to the scientific background of the study and the reliability of data. As explained in chapter 1, the scope of this study regards the pre-diffusion phase that consists of time period between invention and (first) market introduction. The latter assumption was adopted from the model of Ortt and Schoormans (2004), which depicted the development and diffusion of radically new high-tech products. In addition, the unit of analysis concerned a specific definition of a technological product (see section 4.3.2), which is derived from Ortt et al. (2013). The latter assumptions however, guided significantly the selection of the cases. In particular, the investigation of real cases required a priori the existence of reliable data for the definition of the product and the identification of the time period of interest (i.e. the hallmarks). If such data did not exist, then the case would have been of little value.

The second criterion that led to the selection of these specific cases was data availability within the cases. Both RFID and barcode technologies are well documented with regards to their historical development. The availability of evidence allowed me to address a range of factors that affected either positively or negatively the development of the respective technologies. However, this might not have been possible for a large number of cases for which sources of information are scarce or unreliable.

Lastly, the third criterion that guided the choice of RFID and barcode technologies concerned the length of their innovation phases. The assumption taken was that the longer the innovation phase of a technology, the more likely was the observation of a sufficient variety of actors, factors, and interactions that influenced the innovation process from invention to first market introduction. In turn this would serve better the illustrative purpose of the case studies. Thus, technologies with considerably long innovation phase were deliberately chosen.

4.2.4. Data Collection Protocol

Data Sources

The main source of evidence for the historical case studies is secondary published documentation in the form of books, journal articles, reports, and conference proceedings. As stated in Yin (2003), this type of sources is favorable because it allows a repetitive interpretation and a broad coverage in terms of the time period and the range of settings, but at the same time it may suffer from selection bias of the researcher or a reporting bias associated with the author of the source. Moreover, the use of multiple sources will allow the exclusion of data with conflicting sources from the analysis. This type of corroborative strategy can be supported by *data triangulation*. Finally, the creation of a *case study database* that includes both quotes from the documents that have contributed to the data collection, and cases study notes created by the researcher (Yin, 2003).

Search & Data Collection Procedure

A systematic literature review was performed in order to collect relevant data for each of the cases. The search procedure consisted of a primary scientific inquiry in two large databases of scholarly literature, namely Scopus by Elsevier and google scholar by Google. Its aim was to access scientific articles relevant to the historical context of the development of the technology under investigation. For the case of RFID, the aforementioned process also included an inquiry in RFID journal's[2] website. However, a journal dedicated to barcode technologies did not exist. The reason for using both Scopus and google scholar was that despite the significant overlap between their databases, the latter includes a larger number of

[2] Note: RFID Journal is an independent media company focusing specifically on RFID technology and its business applications.

records. In addition, the search in google scholar included citations, whereas this was not the case for the search via Scopus.

In order to screen the articles that were retrieved, several levels of screening were used. Initially by reading the title, then by reading the abstract, and finally by reading the full text. These were the following:

- Inclusion Criteria: historical perspective related to the technological field; AND development-innovation-commercialization perspective related to the history technological field; AND project, organization or market perspective related to the history of the development of the technological field; AND (f)actor(s)-related perspective with regards to the development of the technological field

- Exclusion Criteria: technical analysis of a specific area of development or application of the technological field; focus on more recent or future trends; focus on the market of a specific country; bibliometric analysis; article was not written in English; access to article required payment

Note that for simplicity's sake, the screening criteria were kept stable for all the levels, although some of them were automatically ruled out after each level (e.g. the language of the article could be identified before realizing that the full-text could not be read).

After the primary search was concluded and the selected sources were analyzed, a secondary search that targeted more specific details within the cases took place. This search concerned for example a specific actor (e.g. a scientist or a company) or a specific factor (e.g. a law or a patent). The process was more informal and iterative, and it was performed using "google search", where the first 100 results were examined. Naturally, here the bias of the researcher played a more significant role than in the case of the primary search. Nonetheless, the vast majority of the articles that were used as sources emerged from the primary search.

The primary search process for RFID is clarified by Figures 4-2, 4-3 and 4-4. Each figure is per database. Note that in total, 14 articles were used as data sources for the RFID case since the different searches resulted in two common articles. An overview of the primary search process for the RFID case is presented by Figure 4-5. A similar process was conducted for the barcode case.

Scopus Search

Steps for Data Collection:

Step 1: *Identification - Database Searching – Scopus*

Search Strings:

- 1st Search Field: "RFID" OR "Radio Frequency Identification"
- 2nd Search Field – AND: "Histor*" OR "Evolution"

Search Field Type: Article Title, Abstract, and Keywords

Subject Areas: Physical Sciences; Social Sciences and Humanities

Number of Articles Identified for Consideration: 152

Step 2: *Screening - Review of all articles identified in Step 1*

1st Level Screening of Articles: by reading title

- Articles Screened: 152
- Articles Excluded: 140
- Eligible Articles: 12

2nd Level Screening of Articles: by reading abstract

- Articles Screened: 12
- Articles Excluded: 6
- Eligible Articles: 6

3rd Level Screening of Articles: by reading the full text

- Articles Screened: 6
- Articles Excluded: 2
- Eligible Articles: 4

Step 3: *Inclusion – Specification of the articles to be included in qualitative synthesis*

Result: 4 articles were selected as data sources.

Figure 4-2 Primary search via Scopus – RFID case

Google Scholar Search

Steps for Data Collection:

Step 1*: Identification - Database Searching – Google Scholar*

Search Strings:

- 1st Search: "RFID" AND "History"
- 2nd Search: "RFID" AND "Evolution"

Search Field Type: Article Title

Include Patents: "NO"

Include Citations: "YES"

Number of Articles Identified for Consideration: 95

Step 2*: Screening - Review of all articles identified in Step 1*

1st Level Screening of Articles: by reading title

- Articles Screened: 95
- Articles Excluded: 73
- Eligible Articles: 22

2nd Level Screening of Articles: by reading abstract

- Articles Screened: 22
- Articles Excluded: 10
- Eligible Articles: 12

3rd Level Screening of Articles: by reading the full text

- Articles Screened: 12
- Articles Excluded: 3
- Eligible Articles: 9

Step 3: *Inclusion – Specification of the articles to be included in qualitative synthesis*

Result: 9 articles were selected as data sources.

Figure 4-3 Primary search via Google Scholar – RFID case

RFID Journal Search

Step 1*: Identification - Database Searching – RFID Journal*

Search String: RFID AND History
Inclusion of the first 100 hits

Step 2*: Screening - Review of all articles identified in Step 1*

1st Level Screening of Articles: by reading title

- Articles Screened: 100
- Articles Excluded: 97
- Eligible Articles: 3

2nd Level of Screening of Articles: by reading abstract

Articles without abstract.

3rd Level of Screening of Articles: by reading full text

- Articles Screened: 3
- Articles Excluded: -
- Eligible Articles: 3

Step 3: *Inclusion – Specification of the articles to be included in qualitative synthesis*

Result: 3 articles were selected as data sources.

Figure 4-4 Primary search via RFID Journal – RFID case

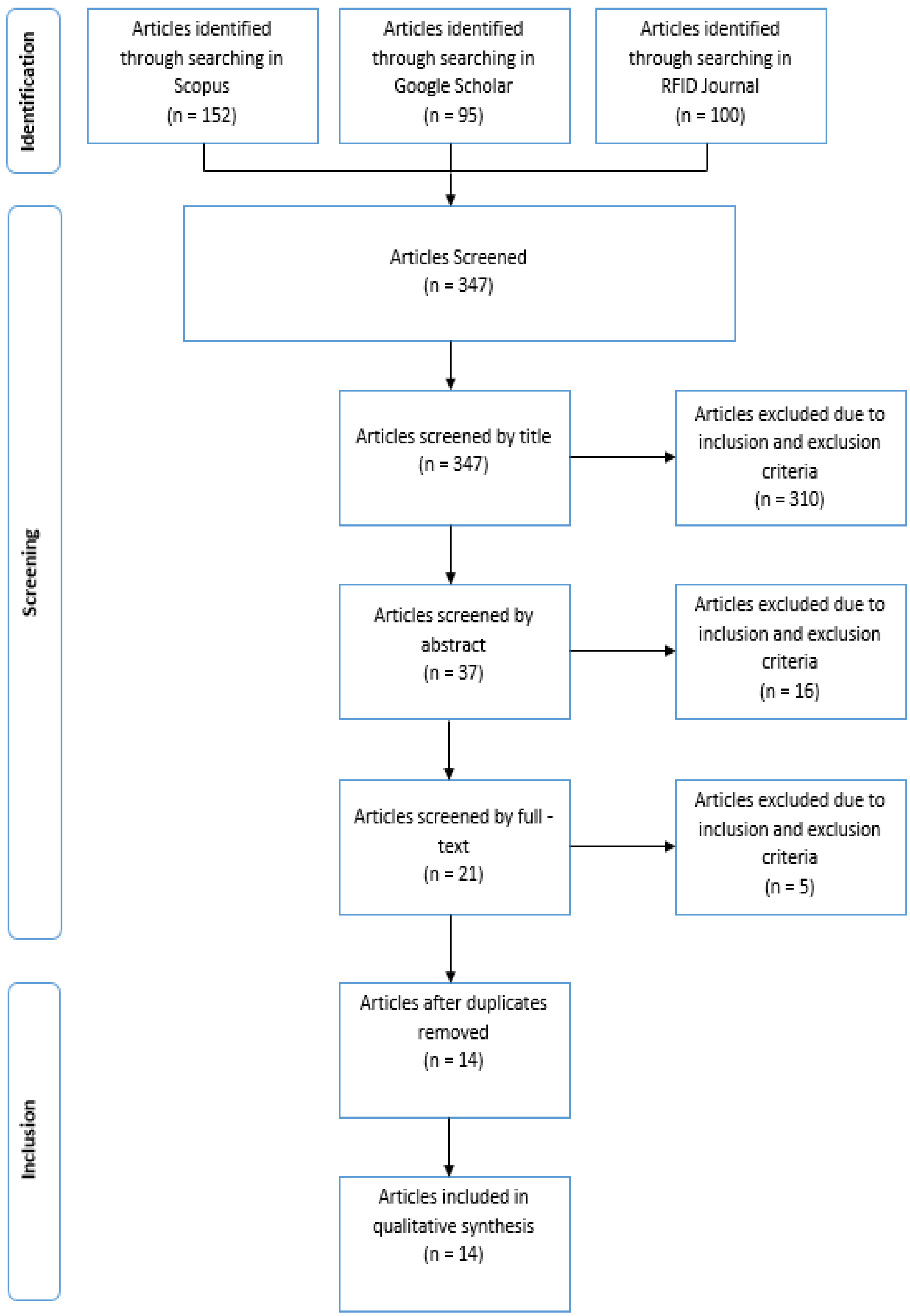

Figure 4-5 Overview of primary search – RFID case

4.2.5. Data Analysis Approach

Following Yin's (2003) advice, the analysis of the case studies' evidence will be performed by: (a) using analytic data manipulation techniques, such as chronologically placing the barriers and facilitators, as well as the hallmarks of invention and first market introduction of the technology investigated; (b) taking into account the theoretical propositions that were developed in chapter 3; (c) operating a cross-case analysis that aims at recognizing patterns, which will be assisted by a presentation of the data across a uniform framework in the form of a table; and (d) attempting to identify rival interpretations of the data.

4.2.6. Overview of Case Study Report

Table 4-1 presents an outline of the content of the case study report. It consists of a preliminary design of the different sections and their respective description.

Table 4-1 Overview of case study report (for each case)

Section	Content
1. Introduction	Definition of product and identification of invention and first market introduction hallmarks
2. Actors and Factors: Barriers and Facilitators	Identification of actors and factors and interpretation of their type of influence: Barriers prevent market introduction, while facilitators can bring the technology closer to the market
3. Interaction among barriers and facilitators	Identification and interpretation of interrelationships barriers and facilitators
4. Conclusion	Answers to the research questions of the study

4.2.7. Case Study Questions

Specific questions will be applied to each of the cases (see Table 4-2). These questions reflect the purpose of the case studies within the research design, and have been formulated after sub-dividing the research questions of the study into topics.

Table 4-2 Case study questions (for each case)

Section	Questions
1. Introduction	a) Define the product by means of: its functionality; the technological principle(s) based on which it functions; and the main components in the system (i.e. a first level of sub-systems). b) Identify the invention (Hallmark 1) by means of the actors involved and the time it took place. c) Identify the market introduction (Hallmark 2) by means of the actors involved and the time it took place.
2. Factors: Barriers and Facilitators	a) Identify the actors and factors that affected the development of the technology between Hallmark 1 and Hallmark 2, and place them in chronological order. b) Categorize the actors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators. c) Categorize the factors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators.
3. Interaction among Barriers and Facilitators	a) Interpret how actors interact within and across levels by identifying mechanisms that work in favor or against development. b) Interpret how factors interact within and across levels by identifying mechanisms that work in favor or against development. c) Depict (visually) interactions among factors
4. Conclusion	a) Determine the contribution of the results of the case study towards answering the research questions of the study.

4.2.8. Visualization Protocol

Figure 4-6 presents the visualization protocol for illustrating: the hallmarks of invention and market introduction, the factors as barriers and/or facilitators at multiple levels, and interactions among them. The interactions among actors are not illustrated graphically, but instead discussed. This decision was taken because such interactions take more complex forms, for which a uniform way of visualization was not possible.

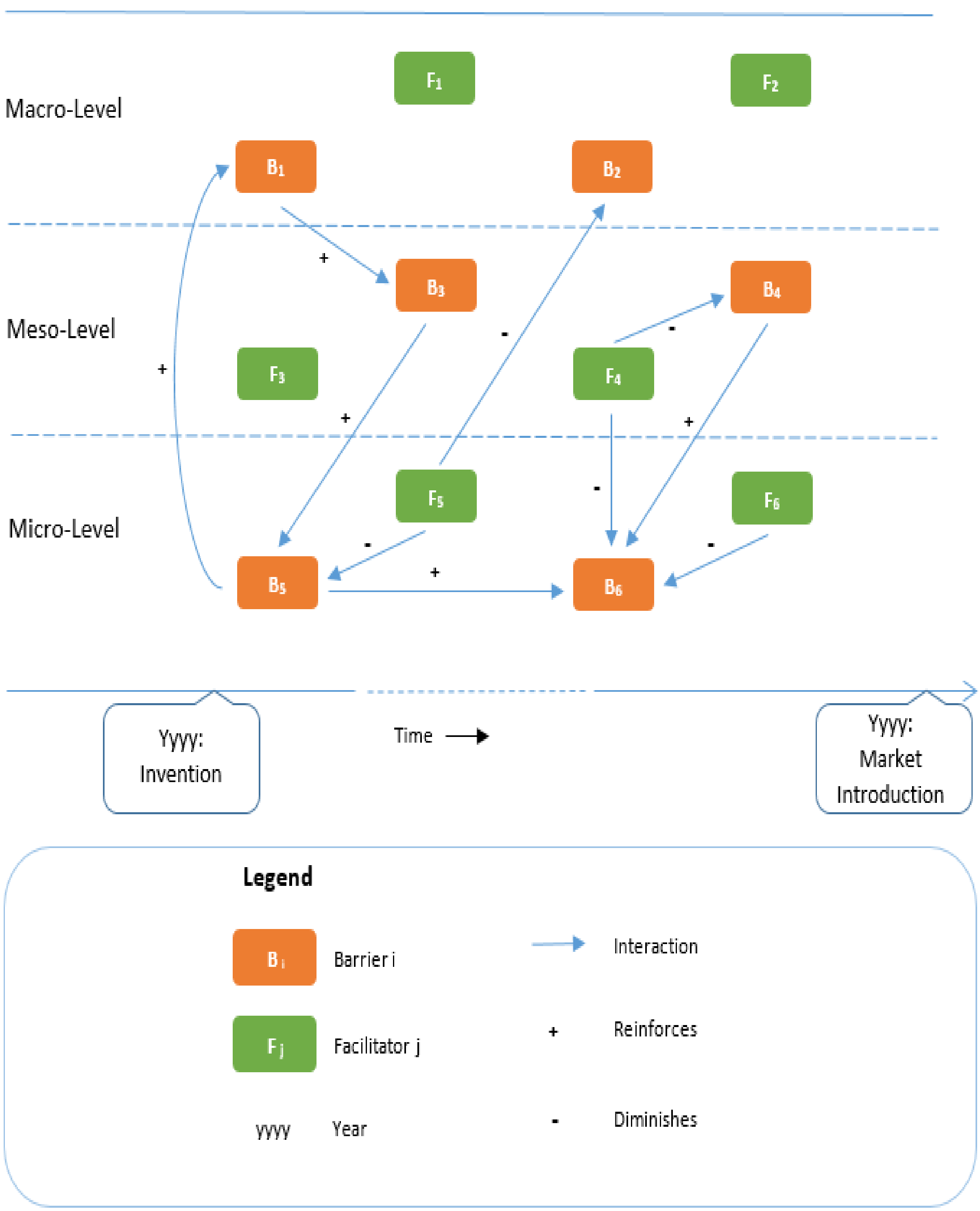

Figure 4-6 Visualization protocol for barriers, facilitators and interaction

4.2.9. Tests to Establish the Quality of the Design

According to Yin (2003), the following tests should demonstrate the quality of the research design: (1) c*onstruct validity* (i.e. the use of appropriate operational measures for the concepts studied); (2) i*nternal validity* (i.e. the establishment of a causal relationship); (3) e*xternal validity* (i.e. the degree to which generalization of the results of the study can be achieved); and (4) r*eliability* (i.e. the demonstration that the research process can be repeated). These tests, however, are more suitable for quantitative and explanatory research, while, this is an exploratory study that concerns highly qualitative concepts. Thus, it would be fruitless to discuss these tests with regard to the quality of the research design that has been followed in this paper. These tests are discussed solely as a reflection on the current research design and with respect to future research (see sub-section 5.5).

With regard to the case study design that has been employed by this paper, the following strategies aim improve its quality and, thus, the trustworthiness of the findings:

- examination of multiple sources information during the data collection process (i.e. data triangulation)
- use of a case study protocol, which includes: an outline of the case study report, the data collection procedures, the case study questions, and the approach of reporting and presenting the results
- creation of a case database that comprises of the collected data and the details of the corresponding reports

4.3. Case A: RFID

4.3.1. Introduction

a) Define the product by means of: its functionality; the technological principle(s) based on which it functions; and the main components in the system (i.e. a first level of sub-systems).

Today RFID is a general term referring to a family of technological products or systems that are used in order to remotely identify assets in an automatic way. Assets can be objects, people or livestock. RFID is often compared to the earlier bar code technology because it provides advancements with regard to "non-optical proximity communication, information density, and two-way communication ability" (Roberts 2006, p. 18). RFID allows monitoring assets remotely "without requiring a line of sight" (Want, 2006, p. 25). Furthermore, modern RFID systems "support a larger set of unique IDs, can incorporate additional data such as manufacturer, product type, and even measure environmental factors such as temperature" (Want, 2006, p. 25). RFID applications vary "from the familiar building access control proximity cards to supply chain tracking, toll collection, vehicle parking access control, retail stock management, ski lift access, tracking library books, theft prevention, vehicle immobilizer systems and railway rolling stock identification and movement tracking" (Roberts 2006, p. 18).

A typical RFID system (see Figure 4-7) incorporates the following basic components (Roberts, 2006; Domdouzis et al., 2007; Lumpkins, 2015):

- an RFID tag (also called as transponder);
- a tag reader (also called as base station or interrogator) that incorporates an antenna, a transceiver, and decoder; and
- a host system or a connection to an enterprise information system.

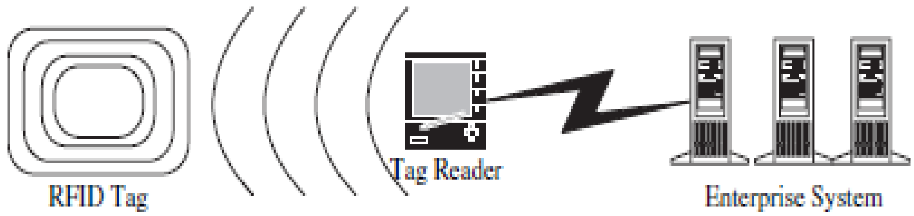

Figure 4-7 A typical RFID system (Roberts, 2006)

The communication of these components can be understood in the following way (Wu et al., 2006, p. 1317): "The tag contains unique identification information of the item to which it is attached; the reader emits and receives radio waves to read the information stored in the tag, and the data-processing equipment processes all the collected data." Note that RFID systems can discern many different tags that are located in the same general area without the need for human intervention (Want, 2006).

The operation of RFID systems is based on the detection of radio signals (Domdouzis et al., 2007). The tag reader produces an electromagnetic zone by emitting radio waves, which in some cases can reach more than 100 feet. The radio waves consist of an interrogating signal requesting identification data from one or more tags that are located within its range. The RFID tag, which is found in the zone, is responsible for responding to the interrogating signal by sending corresponding data in the form of an encoded modified signal (see Figure 4-8). This is done by either reflecting back the signal (passive system) or broadcasting a signal (active system). The tag reader decodes the data that is encoded in the RFID tag, and forwards the resulting information to the host system in order to be processed and stored.

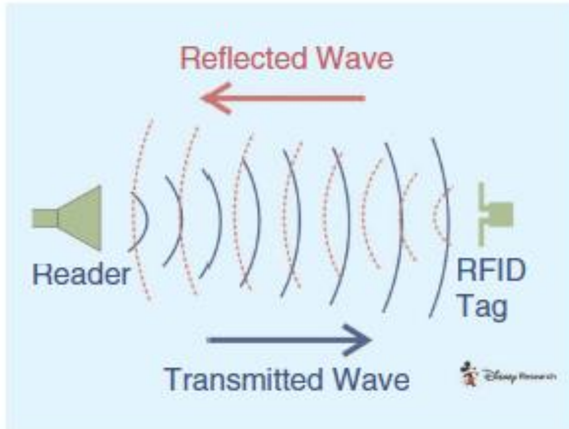

Figure 4-8 RFID operating principle (Courtesy of Disney Research) as in Lumpkins (2015)

As it can be derived from the previous analysis, there are different ways to define the unit of analysis for an RFID-based product. This is important to note because such definition affects significantly the interpretation of the pattern of development and diffusion for RFID technology in terms of the respective hallmarks (i.e. the time of invention and (first) market introduction). For the purpose of this paper, I have followed a narrow definition of RFID, which suggests that: the operating principle of RFID is the communication by means of the reflection of radio signals (passively or actively) in order to identify an asset and retrieve relevant data. In addition, with regard to the commercialization of RFID-based products the focus is on applications for civilians (i.e. the use of RFID technology for military purposes is not considered as a market application). Thus, the descriptions of the Hallmark 1 and Hallmark 2 that follow take into account the former considerations.

b) Identify the invention (Hallmark 1) by means of the actors involved and the time it took place.

The origins of RFID technology can be traced back to World War II. In this period, many of the countries involved in the war were employing radar systems to give notice of approaching aircrafts. However, the problem was that there was no way to identify whether the planes were pilots returning to the base (friends) or enemies (foe). According to Violino (2005, p.1) “the Germans discovered that if pilots rolled their planes as they returned to base, it would change the radio signal reflected back”. This enabled them to distinguish between own and allied planes. However, it was the British in the mid-1940s that first put transponders on their aircrafts, so that they would be able to correspond to interrogating signals sent by the base station. These long-range transponder systems, which are often referred to as Identity Friend or Foe (IFF) systems, were the first RFID-related technologies to have been explored. The first use of the IFF systems is considered here as the invention of RFID technology since it was the first demonstration of a working system that used transponders and interrogating signals in order to remotely collect information about an object based on the detection of radio waves.

c) *Identify the market introduction (Hallmark 2) by means of the actors involved and the time it took place.*

The first commercial implementation of RFID technology was realized about 25 years later in the late 1960s. It was back then that companies such as Sensormatic, Checkpoint and Knogo developed simple RFID-based systems to be used as an anti-theft measures in retail stores (Dobkin, 2013). These systems, which are referred to as Electronic Article Surveillance (EAS) systems, were commercialized by the early 1970s (Miles, 2008) and they are still widely adopted. The EAS tags carried 1 bit of digital information, which could be either on or off, thus allowing to "determine whether a product from a retail stored had been paid for or not" (Violino, 2005, p.1).

4.3.2. Actors and Factors as Barriers and/or Facilitators

a) *Describe the key actors and factors that affected the development of the technology between Hallmark 1 and Hallmark 2 in chronological order*

The existing documentation shows that there were various factors and actors that affected the development and commercialization of RFID. From a chronological perspective, the time period after invention and before market introduction can be summarized as follows (Landt, 2001): the 1940s and 1950s were primarily characterized by early exploration activities and experiments in laboratories; the 1960s by theoretical developments and the initiation of application trials in different fields; the 1970s by an acceleration of RFID developments, an increase in field tests of the technology, and very early adoption of simple RFID concepts; and the 1980s by mainstream commercial applications.

In 1948 Harry Stockman, who was at the time working for the Air Materiel Command in Massachusetts, published a paper exploring RFID technology. According to many sources (Domdouzis et al., 2007; Reyes and Frazier, 2007; Landt, 2001; Dobkin, 2013; and Jamali, 2010), his work, which was entitled "Communication by Means of Reflected Power'', is considered a milestone towards the development of RFID technology. The paper concerned an investigation of the "use of backscattered radiation to communicate substantial information" (Dobkin, 2013, p. 10). A major conclusion of the paper (as stated in it) was that "evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored" (Landt, 2001, p. 4). Technological progress related to "the transistor, the integrated circuit, the microprocessor" as well as, advances in communication networks, and business operations that took place in the coming decades proved crucial for the implementation of RFID concepts (Landt, 2001, p. 4).

In the 1950s, significant scientific knowledge related to RFID was developed. Research and papers by academics and other scientists intended to demonstrate the uses of radio frequency energy in order to remotely identify objects (Violino, 2005). Notable works concerned (Landt, 2001; Dobkin, 2013): the 'Application of the microwave homodyne' by Vernon, (1952); the extraction of DC from RF by Crump (patent US 2,943,189); and 'Radio transmission systems with modulatable passive responder' by Harris,

(1960) (patent: US 2,927,321). It is also noteworthy that the patent by Harris (1960) aimed at developing a low-cost wireless telephone system.

In the 1960s, advances in radio frequency communication by means of scientific work and inventions continued (Landt, 2001). In 1963-64 R. F. Harrington investigated the electromagnetic theory associated to RFID, by presenting two papers "Field measurements using active scatterers" and "Theory of loaded scatterers". Other inventions related to RFID technology were: "Remotely activated radio frequency powered devices" by R. Richardson in 1963, "Communication by radar beams" by O. Rittenback in 1969, "Passive data transmission techniques utilizing radar beams" by J. H. Vogelman in 1968 and "Interrogator-responder identification system" by J. P. Vinding in 1967.

Development and early commercialization efforts were also initiated in the late 1960s. According to Dobkin (2013), it was then that the Sandia National laboratories initiated the production of “passive identifying systems operating at radar like frequencies” (p. 12). Such technology was “directed towards animal identification”, although it is also suggested that “the original motivation was the preservation of cowhide otherwise defaced by branding” (p. 13). During the same period of time, companies developed and marketed the first EAS systems based on RFID. Unfortunately, there is no detailed description about the setting within which the development and commercialization of such systems took place, but only little evidence.

According to Easlabel (2015), in 1964 Jack Welsh conceived the first EAS system after being asked by his cousin Ronald Assaf to come up with a way of detecting thieves that would attempt to steal objects in his supermarket in Ohio. Welsch, who already had experience with electronic tags for products, probably came up with an idea similar to what we know as the EAS system. Two years later in 1966, Assaf founded Sensormatic Electronics Corporation. However, the first EAS system that was based on RFID technology was designed the same year by Arthur Minasi, founder of Knogo North America Inc. Minasi, who was an electrical engineer and as a boy used to shoplift, “crafted a plastic tag embedded with a metal coil, which was a really small antenna that responded to radio frequencies. He also built a portal to surround a doorway which set off an alarm” (Agon, 2015, n.p.). It is also worth noting that others had attempted before Minasi to create similar anti-theft systems “by loading tags, for example, with small amounts of radioactive material, which would be detected by a Geiger counter at the store’s exit. Reasonably the government prohibited that” (n.p.).

Around the same time, several developments took place: Sensormatic “developed a microwave-based (UHF) EAS system which was primarily targeted at department and apparel stores” and “George J Lichtblau developed Swept RF technology and licensed his patents to Checkpoint which created a commercial product” (n.p.) By the early 1970s Knogo, Sensormatic, and Checkpoint had marketed EAS systems based on RF.

Noticeably, advanced RFID systems could already be demonstrated by the early 1970s, due to the significant decrease in the cost of electronic components (Dobkin, 2013). Many applications that had been envisioned by then concerned traffic management including “toll collection, toll parking, dynamic traffic control, vehicle identification, trucking location, and surveillance” (p. 15). For example, Mario Cardullo had already envisioned in 1969 the application of RFID for the rail industry in the U.S. During that period a

CARTRACK optical system was being tested in order to keep “track of tens of thousands of rail cars across tens of thousands of kilometers of track” (p. 15). This system used a circular barcode technology, and was thus facing several problems when the optical identification was obstructed, mainly because of weather conditions.

However, such advanced RFID applications were mostly hampered by barriers related to “cost, regulation, and institutional risk, though early observers were also already concerned about driver privacy” (Dobkin, 2013, p. 15). The cost barrier was gradually removed throughout the 1970’s and 1980’s when “semiconductor manufacturing improved dramatically” and “the cost of virtually all electronic goods fell commensurately” (p. 15).

b) Categorize the actors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators.

The aforementioned historical analysis reveals key actors that played a role in the development of RFID technology from invention to market introduction. Table 4-3 presents the respective actors, followed by an interpretation of the way they functioned as barriers and/or facilitators.

Table 4-3 Actors that affected the development of RFID

Actor	Function
Macro-Level	
1. Scientists	Facilitator: Scientists enhanced the progress of the knowledge about the technology and potential application fields. Their work resulted in published papers or patents. Although, their background is not well documented, it is assumed that these actors were possibly related to academia or other R&D institutions.
2. Autonomous Entrepreneurs	Facilitator: Autonomous entrepreneurs came up with new ideas about potential market applications of a new technology, but also might discover and/or design a new product concept.
3. Potential Users (Early Adopters)	Facilitator: The exploration of a new business opportunity related to an application of the technology was enhanced when a potential user communicated a market need. This is related to the concept of lead user.
4. Government	Facilitator: The U.S government was funding a research institute that was engaged with the development of RFID systems. Additionally, the government affected indirectly the emergence of an application of the technology as it prohibited the application of other technologies that would satisfy the same market need.
5. Research Institute	Facilitator: A research institution (which in this case was a national laboratory) was engaged in the production of new technology for a specific application field. It is logical to assume that considerable research had preceded.
Meso-Level	
1. Companies – Developers	Facilitator: Companies undertook projects to develop a marketable product incorporating the technology. In two of the three cases that are visible the companies were new ventures initiated by entrepreneurs. In the third case the company was already established and bought patents from an autonomous entrepreneur.
Micro-Level	
More documentation is required in order to derive relevant conclusions.	

c) *Categorize the factors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators.*

Table 4-4 introduces the factors that affected the development of the RFID technology. The interpretation of the way they functioned as barriers and/or facilitators is also included.

Table 4-4 Factors that affected the development of RFID

Factor	Function
Macro-Level	
Technology	Barrier: In the 1940s and 1950s the technology was imperfect and considerable R&D was required in order for knowledge of applications to develop. Facilitator: Advances related to the transistor, the integrated circuit and the microprocessor during the 1960s and 1970s increased the potential of the technology, and thus its applicability as well.
Supply & Production (Networks)	Not found to play a role.
Infrastructure & Maintenance (Networks)	Not found to play a role.
Psychological & Cultural Factors	Not found to play a role.
Social Networks	Not found to play a role.
Environmental & Social Effects	Not found to play a role.
Government Policy	Not found to play a role.
Legislation & Regulation	Barrier: A barrier that hampered directly the development of the technology was the concerns about the privacy of potential users in the late 1960s. Facilitator: Other competitive technological systems that had been designed to satisfy the same market needs during the 1960s were prohibited by the government. This was an indirect facilitator to the application of the technology in the late 1960s.
Economic Factors	Barrier: The increased cost of electronic components of the technology inhibited its application and commercialization during the 1950s and 1960s.
Institutional Risk *New Factor*	Barrier: During the late 1960s and early 1970s, Institutional risk was presented as a factor that hampered the implementation of visions of potential applications of the technology in some cases. It is assumed that it concerned market-related institutions.
Competition *New Factor*	Barrier: In the late 1960s, a competitive technology had just been introduced to the market and was used by early adopters (in this case the railroad industry). Thus the application of the technology to satisfy the same market need became more difficult.
Meso-Level	
Scientific Knowledge & Firm-Specific Techniques	Facilitator: From the mid-1940s till the end of the 1960s, scientists enhanced the development of knowledge of the technology and its applications mainly through the publication of scientific papers. In the

	mid and late 1960s, companies also developed and marketed products based on the proprietary systems, which are assumed to be the result of scientific knowledge and firm-specific techniques.
Technical Systems	Not found to play a role.
Managerial Systems	Not found to play a role.
Organizational Culture & Values	Not found to play a role.
Financial Resources	Not found to play a role.
Micro-Level	
Opportunity	Barrier: In the late 1960s some opportunities for applications of advanced technological systems could not be explored because of the increased cost of electronic components. Facilitator: In the late 1960s, some actors managed to commercialize simple technological products for a different application.
Product Concept & Definition	Not found to play a role.
Project Planning	Not found to play a role.
NPD process	Not found to play a role.

4.3.3. Interaction among Actors and Factors as Barriers and/or Facilitators

a) Interpret how actors interact within and across levels.

In line with the description of Table 4-4, several ways in which actors interact with each other can be derived. These are explained as follows:

- The role of actors can change in the course of the development of the technology*: Companies-Developers* were founded by *Scientists* or *Autonomous Entrepreneurs* that had a product vision and were willing to explore a market opportunity.
- Actors license out proprietary technology to other actors: *Companies-Developers* acquired patents by *Scientists* or *Autonomous Entrepreneurs* in order to develop and market a product based on them.
- Actors communicate market needs and potential solutions with each other: *Potential Users (Early Adopters)* communicated market needs to *Scientists* or *Autonomous Entrepreneurs,* and thus potential applications of the technology were revealed.
- Actors leverage on resources of other actors*: Research Institutions* allowed *Scientists* to undertake R&D activities by providing them with the necessary resources.

b) Interpret how factors interact within and across levels by identifying mechanisms that work in favor or against development.

The following mechanisms of interaction among barriers and facilitators were identified:

Mechanism 1 - Barriers reinforce other barriers at another level: The lack of sufficient knowledge about the *Technology* and its applications meant that there were no *Opportunities* for NPD projects.

Mechanism 2 - Barriers diminish facilitators at another level: Barriers related to *Economic Factors, Legislation and Regulation, and Institutional Risk* did not allow the exploitation of *Opportunities* for several applications of the technology.

Mechanism 3 – Facilitators reinforce facilitators at another level: Advances related to S*cientific Knowledge and Firm-specific Techniques* allowed the emergence of *Opportunities* for NPD projects.

c) Depict interactions among barriers and facilitators.

Figure 4-9 illustrates the aforementioned interactions among barriers and facilitators.

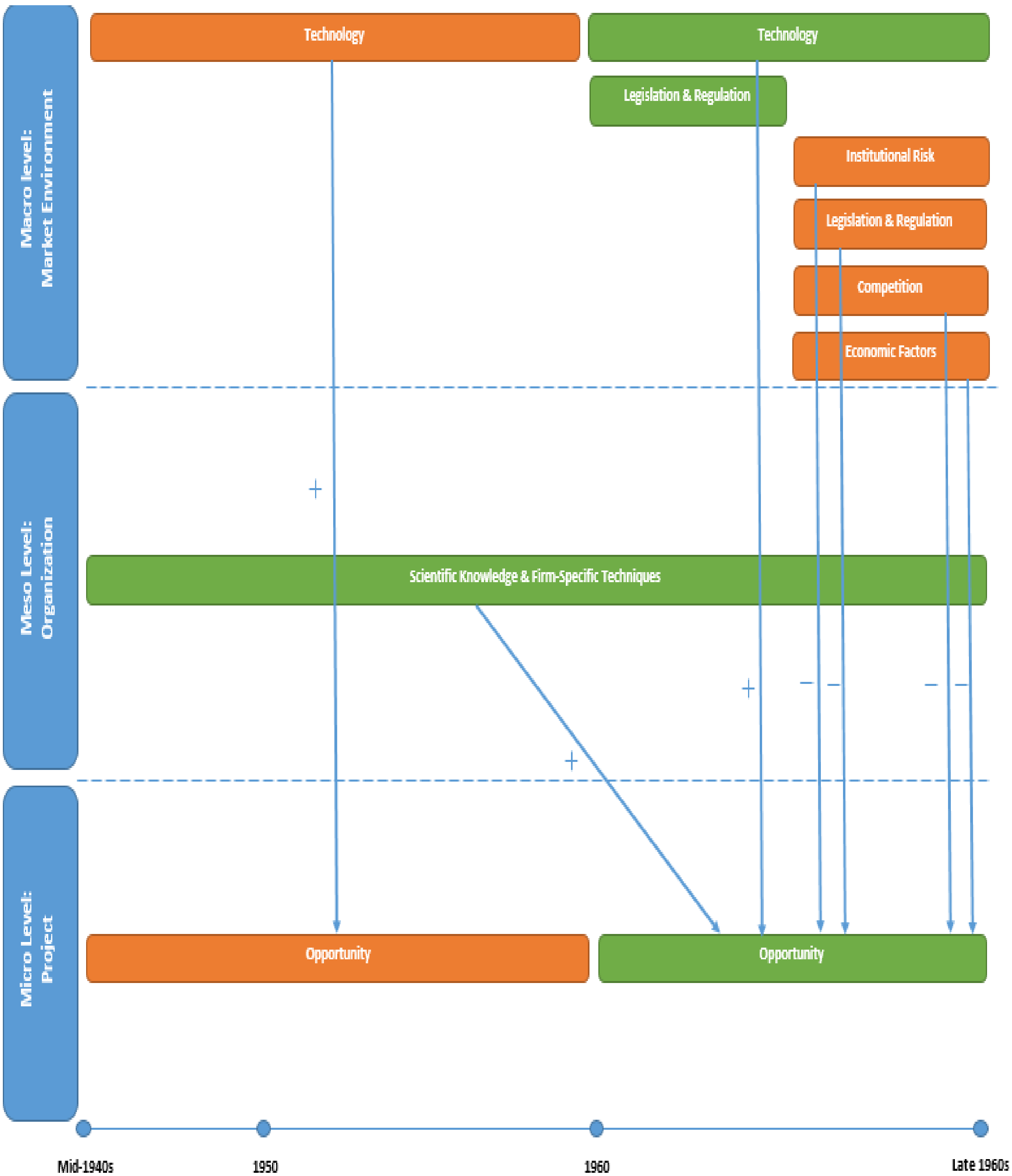

Figure 4-9 Interactions among barriers and facilitators for the RFID case

4.3.4. Conclusion

a) Determine the contribution of the results of the case study towards answering the research questions of the study.

1. What are the key actors and factors that either hamper or facilitate the development of the invention of a new high-tech principle into a marketable radical high-tech product?

The analysis of existing documentation revealed several actors that facilitated the development of RFID technology. These are the following:

Macro-level actors:

- Facilitator: Scientists
- Facilitator: Autonomous Entrepreneurs
- Facilitator: Potential Users (Early Adopters)
- Facilitator: Government
- Facilitator: Research Institutes

Meso-level:

- Facilitator: Companies – Developers

Two basic observations can be made with regard to the previous list of actors. Firstly, according to the theoretical analysis of chapter 2, only macro and meso-level actors were identified. This can be attributed to the lack of available data in order to derive conclusions about actors at the micro-level, where more specific roles within a project are under investigation. Secondly, there were no macro-level actors effectively hampering the development and commercialization of RFID technology. This can be expected since the application of many technologies is opposed after their first market introduction or application, when their social and environmental effects are revealed. Another possible explanation is that the fist market application of the technology regarded a market need that had not been satisfied by other products previously. Thus, there were no interests vested in other technological solutions.

Regarding the factors that affected the development of RFID technology, these were the following:

Macro-level factors:

- Barrier/Facilitator: Technology
- Barrier/Facilitator: Legislation & Regulation
- Barrier: Economic Factors
- Barrier: Institutional Risk
- Barrier: Competition

Macro-level factors:

- Barrier/Facilitator: Scientific Knowledge & Firm-Specific Techniques

Micro-level factors:

- Barrier/Facilitator: Opportunity

The analysis of RFID technology resulted in two new factors that had not been identified by the literature review in chapter 3. These are *Institutional Risk* and *Competition*. Both of these factors are discussed later as part of the cross-case analysis section (see section 4.5.2).

2. How are these barriers and facilitators interrelated?

The actors were found to interact in the following ways:

- The role of actors can change in the course of the development of the technology (e.g. from scientists to founders of companies)
- Actors license out proprietary technology to other actors (e.g. scientists or autonomous entrepreneurs license out technologies to established companies)
- Actors communicate market needs and potential solutions with each other (e.g. a potential user of the technology requests a new product to satisfy his market need and an engineer responds)
- Actors leverage on resources of other actors (e.g. scientists who work within research institutions)

In addition, the following mechanisms between factors were identified (for specific examples see sub-section 4.3.3):

- Barriers reinforce other barriers at another level
- Barriers diminish facilitators at another level
- Facilitators reinforce facilitators at another level

3. What strategies can be proposed to organizations seeking to introduce a radical high-tech product for the first time into the market?

The analysis of the RFID case showed that a considerable part of the innovation process did not take place within companies. Instead, the central actors were autonomous researchers, scientists and entrepreneurs, as well as, research institutes. Companies were active only in the last 5 years of the innovation phase. Interestingly, two of the three companies were new ventures, while one company, which was already established, developed an RFID-based product around a patent that they acquired from a scientist. Based on the aforementioned observations, two following two strategies can be proposed to companies:

Collaboration with other Knowledge Producing Institutions: Significant knowledge might be required for NPD. In many cases in the course of the development of RFID, innovation took place in labs, and other knowledge and research institutions that were probably co-funded by the government. It is also logical to assume that inventors and researchers that worked on RFID-related ideas were associated with universities, although there is a lack of data with regard to their background. Since government and academia are central actors in innovation, companies should work closely with them in order to exploit opportunities that emerge. Such opportunities take the form of both new knowledge and technologies. Most of the time, the government is responsible for funding research institutes and academia. In turn, the latter are responsible for the production of knowledge, basic technology, and human capital. Universities also churn out entrepreneurs. Companies, by both investing in knowledge producing institutes and participating in other types of partnerships with them, might be better positioned to receive useful knowledge and human capital. Such collaboration with knowledge producing institutions can take many forms such as: incubators, centers of excellence, technology networks and platforms, convergence laboratories, or technology centers and parks.

Strategic Patent Acquisition: Early R&D efforts by scientists or autonomous entrepreneurs might result in the development and demonstration of techniques or products based on a new technology. Companies should be able to identify such efforts and attempt to exploit potential market opportunities based on the acquisition and application of the right patents. In this respect, external-scanning processes might be crucial. Finally, companies should be aware of: the specific conditions under which the acquisition of patents results in successful early market introduction; and the criteria based on which individual entrepreneurs or scientists opt out between the foundation of a new company and licensing out their patents to established companies.

Another interesting observation resulting from the RFID case study regards the role of potential early adopters in the development of the technology. For example, Assaf, who wanted to come up with a way of detecting thieves in his supermarket in Ohio, was the same person who founded Sensormatic Electronics Corporation, which was among the first to commercialize an EAS system based on RFID. Such evidence indicates another strategy relevant to the innovation phase:

Working together with Potential Early Adopters: When innovation takes place in more market oriented environments; potential users play a crucial role not only by communicating market needs, but also by assisting the development of knowledge with regard to the application of the technology. Thus, companies should consider the benefits derived from the involvement of potential users in the development of new products. This however might not be possible in situations that are more research oriented, where the potential applications of a technology might be unknown.

4.4. Case B: Barcode

4.4.1. Introduction

a) Define the product by means of: its functionality; the technological principle(s) based on which it functions; and the main components in the system (i.e. a first level of sub-systems).

The term Barcode refers to an AIDC technology based on "a wired line of sight" (Modgil et al., 2012). Barcode systems provide a useful method to read, process, and record data (e.g. about an object) using electronic equipment (Gao et al, 2007). The distinctive feature of such systems is the representation of the information that is processed. Such representation takes a visual format and comprises a way to encode numbers and letters (i.e. text information) in a sequence of symbols (i.e. codes) that are machine-readable. In this way, barcode technologies allow for automatically entering data, without the need for using a keyboard or any other manual action (Gao et al, 2007). Today different types of barcode technologies are used for a wide variety of applications in fields such as "manufacturing, postal, transportation, government, health care, retail business, trade show, and automotive business" (Gao et al, 2007).

Barcode systems operate based on the reflection of light on to a code, which is "a combination of high and low reflectance regions of the surface of an object" (Kato et al., 2010). The code consists of an array of lines (i.e. bars) or a pattern of homocentric circles varying in widths and spacing, which are used to encode information about an object (see Figure 4-10). In turn, the reflected light is automatically converted into digits of data. In the simplest form of the technology the digits are 1's and 0's. These digits of data characterize the object on which the bar-code is attached. This way information about the object can be collected, processed, and stored. Note that the aforementioned principle refers to linear or one-dimensional codes, although nowadays two and three-dimensional codes are also being used as the technology has progressed.

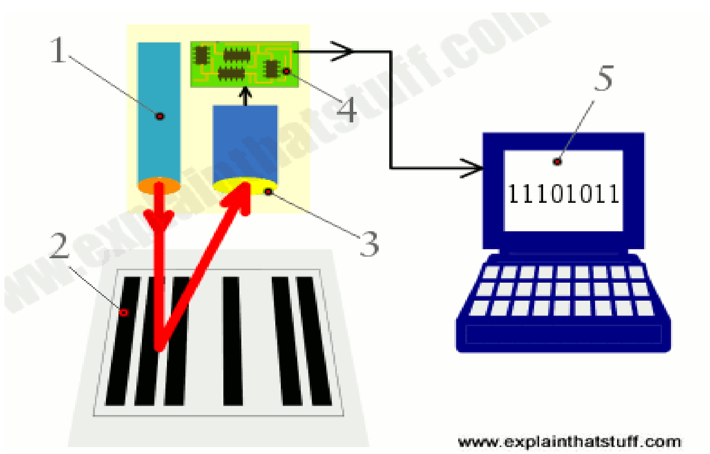

Figure 4-10 Operating principle for a typical barcode system (Woodford, 2015)

A typical barcode system functions based on the communication of the following (see Figure 4-8): A *scanner* (or barcode reader) is required to read the *code* (or barcode) that is attached to an object. The data retrieved by the scanner, is then processed and stored by an *information system* (or a record system) consisting of a central computer-database.

b) *Identify the invention (Hallmark 1) by means of the actors involved and the time it took place.*

According to Reynolds (n.d.), Norman Woodland, a teacher at the Drexel Institute in Philadelphia, invented the barcode around 1949. The problem that Woodland was trying to solve was related to the development of a system that would "quickly and accurately capture product data at the check-out counter" (n.p.) of a food chain store. This problem was communicated to him by one of his students, Bernie Silver, when the latter overheard a relevant conversation at Drexel. After experimenting with various data collection techniques, and being inspired by the Morse code that was currently used in telecommunications, Woodland came up with the idea of using a series of extended lines of dots and dashes as a representation of the product number. He had created the first linear barcode. In order to read it, he used a sensitive tube on which light would be reflected and translated into numbers. The latter idea was an adaptation of a movie sound system that was being used. They eventually filed a patent application on October 20, 1949.

Several sources suggest that instead of parallel lines, Woodland used homocentric circles for the first barcode so that it could be readable from any direction (Seideman, 1993; Adams, 2013). Such a pattern is referred to as the "bulls-eye" code. However, many types of codes were being investigated by Woodland and Silver, and both patterns were included in their descriptions.

c) *Identify the market introduction (Hallmark 2) by means of the actors involved and the time it took place.*

The first commercial application of barcode technology took place in 1969. It was then that Computer Identics installed its first two barcode systems using a laser beam as a light source (Seideman, 1993). One of the systems was installed in a General Motors in order "monitor the production and distribution of automobile axle units", while the other was set up at a distribution facility operated by General Trading Company in New Jersey in order to "help direct shipments to the proper loading-bay doors". Such systems were advantageous because "the laser light was smaller, cooler and could be moved back and forth rapidly over the code" (Reynolds, n.d.). At the time, their components were handmade, and they relied on very simple bar codes that would carry "only two digits' worth of information" (Seideman, 1993).

4.4.2. Actors and Factors as Barriers and/or Facilitators

a) *Describe the factors that affected the development of the technology between Hallmark 1 and Hallmark 2 in chronological order*

During the 1950s, the most important actor engaged with the development of the barcode technology was Woodland. Woodland and Silver saw their patent (US Patent 2,612,994) granted in 1952. One year earlier Woodland had gotten a job at IBM with a view to further develop the system he had created (Seideman, 1993). Working closely with Silver, they had by then managed to set up a barcode reader that was “the size of a desk and had to be wrapped in black oilcloth to keep out ambient light”. The two basic components of this system were: “a five-hundred-watt incandescent bulb as the light source and an RCA935 photo-multiplier tube, designed for movie sound systems, as the reader”.

Although the system could work, the technology was immature, and several developments would be needed before it could be applied. The main problems were related to the bulb that was used (Seideman, 1993). Only a tiny fraction of the enormous amount of light that it emitted could be read, and the rest was just an “expensive waste”, which could possibly cause “eye damage”. Woodland and Silver were in need of a source able to “focus a large amount of light into a small space”, but at the time the laser had not been invented yet. In addition, a way to transform the output of the process into something useful for the management or customers of retail stores was missing, and the size of the equipment was considered enormous (Reynolds, n.d.).

In the late 1950s, Woodland was trying to convince his bosses at IBM to further develop his technology (Seideman, 1993). However, a consultant hired by company estimated that despite the increased potential, more than five years would be required for the technology to be ready for application. IBM had previously expressed interest on buying the patent that Woodland and Silver had been granted in 1952, however the two inventors thought that the price that IBM offered did not reflect the great possibilities of the technology (Reynolds, n.d.). In 1962, they finally sold the patent to Philco, and between 1962 and 1966 Philco sold the patent to RCA.

Around 1966, RCA executives began to realize the commercial potential of barcode applications in retail stores (Seideman, 1993). Previously, they had attended a conference organized by The National Association of Food Chains (NAFC), who called for “systems that would speed the checkout process” (Adams, 2013). RCA developed a bulls-eye barcode system in collaboration with Kroger grocery chain, who “volunteered itself as a guinea pig” (Seideman, 1993). However, it was only later in 1972 that the system was installed and operating in a Kroger store in Cincinnati.

By the early 1960s, other inventors were trying to develop different methods for identifying products and collecting relevant data. The most notable effort related to the barcode technology, was the “railway car tracking system developed by David Collins of the Sylvania Corporation” (Reynolds, n.d.). Collins having worked in the railroad industry was aware of such market need. Instead of using black bars and spaces as codes, he came up with the idea of a pattern consisting of “groups of orange and blue stripes made of a reflective material, which could be arranged to represent the digits 0 through 9” (Seideman, 1993). A computer that had been built up by Sylvania enabled the processing of the gathered data. Tests for the system began in 1961 by Boston & Maine, and by 1967, a “nationwide standard for a coding system was adopted”. The system was ready to be sold to the railroad industry, but it was only commercialized during the early 1970s without success (Reynolds, n.d.; Seideman, 1993).

Meanwhile, in 1967, Collins envisioned the application of barcode systems beyond the railroad industry (Seideman, 1993). This time his vision included using a “little black-and-white-line” as a barcode for controlling moving goods. However, Sylvania refused to fund him because they thought that they should only focus on the railroad application. They thought that the railroad industry was a big market that would become very profitable for them, and thus, they did not want to invest in other applications. Collins left Sylvania and "co-founded Computer Identics Corporation".

Computer Identics developed barcode systems based on lasers (Seideman, 1993): "A thin stripe moving over a bar code would be adsorbed by the black stripes and reflected by the white ones, giving scanner sensors a clear on/off signal. Lasers could read bar codes anywhere from three inches to several feet away, and they could sweep back and forth like a searchlight hundreds of times a second, giving the reader many looks at a single code from many different angles. That would prove to be a great help in deciphering scratched or torn labels." By mid-1969, Computer Identics had successfully commercialized such systems (US Patent 3673389 and US Patent 3743819) (Adams, 2010).

The technological progress in laser technology and integrated circuits during the late 1960s was crucial for the commercialization of the barcode technology (Seideman, 1993). "Transistors and laser components were getting less expensive, and computer processors continued to shrink in size" (Reynolds, n.d.). Such technologies did not exist when the barcode was first conceived by Woodland and Silver during the late 1940s.

b) Categorize the actors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators.

The aforementioned historical analysis reveals key actors that played a role in the development of barcode technology from invention to market introduction. Table 4-5 presents the respective actors, followed by an interpretation of the way they functioned as barriers and/or facilitators.

Table 4-5 Actors that affected the development of barcode

Actor	Function
Macro-Level	
Scientists	Facilitator: Scientists explored the potential of the technology by building prototypes and demonstrating working principles. In addition, scientists tried to convince companies to further develop the technology.
Potential Users (Early Adopters)	Facilitator: Potential users offered to collaborate with companies with a view to develop the technology. Furthermore, they contributed by testing products that were still in development.
(Actors Representing an) Industry	Facilitator: An association representing an industry communicated a market need to manufacturers by calling them to develop equipment.
Meso-Level	
Companies – Developers	Facilitator: Companies-Developers provided scientists with resources in order to pursue R&D activities. Barrier: Companies-Developers refused to invest further in the development of the technology.
Consultants *New Actor*	Facilitator: A consultant was hired by a company in order to evaluate the potential of a technology for which a patent had been granted to scientists.
Micro-Level	
More documentation is required in order to derive relevant conclusions.	

c) *Categorize the factors at multiple levels (i.e. market environment; organizational; project) and interpret them as barriers and/or facilitators.*

Table 4-6 introduces the factors that affected the development of barcode technology as defined by the scope of this project. The interpretation of the way they functioned as barriers and/or facilitators is also included.

Table 4-6 Factors that affected the development of barcode

Factor	Function
Macro-Level	
Technology	Barrier: During the late 1940s and the 1950s the technology was not ready for application because the only system that existed was cumbersome. Facilitator: In the 1960s technological developments in transistors and lasers enabled the application of the technology.
Supply & Production (Networks)	Not found to play a role
Infrastructure & Maintenance (Networks)	Not found to play a role
Psychological & Cultural Factors	Not found to play a role
Social Networks	Not found to play a role
Environmental & Social Effects	Not found to play a role
Government Policy	Not found to play a role
Legislation & Regulation	Facilitator: In the mid-1960s, the development of standards facilitated the commercialization process of the technology.
Economic Factors	Facilitator: In the late 1960s, lasers became less expensive, and could be used in systems that would be commercialized.
Institutional Risk	Not found to play a role
Competition	Barrier: During the 1960s, other AIDC technologies were also being explored and developed.
Meso-Level	
Scientific Knowledge & Firm-Specific Techniques	Facilitator: In the late 1940s and the 1950s scientific efforts enabled the demonstration of the technology. Moreover, in the mid and late 1960s, companies also developed and marketed products based on the proprietary systems, which are assumed to be the result of scientific knowledge and firm-specific techniques.
Technical Systems	Facilitator: In the early 1960s a scientist managed to demonstrate a system leveraging on a computer that had been developed by a company for which he worked.
Managerial Systems	Facilitator: In the early and mid-1960s, companies bought patents that were developed by other companies. The ability to identify and acquire technologies that were developed externally is attributed to the managerial systems of an organization.
Organizational Culture & Values	Barrier: In the mid-1960s, a company refused to invest in the development of the technology based on a new idea. Instead, they focused solely on the concepts that they had already developed. This

	is interpreted as a risk-averse attitude that impeded the innovation process.
Financial Resources	Barrier: In the mid-1960s, a company refused to fund the development of a product based on an idea developed by one of its employees.
Micro-Level	
Opportunity	Barrier: During the late 1940s and 1950s, the opportunities to apply the technology were constrained by operational problems related to the technology. Facilitator: During the 1960s, opportunities for the application of the technology emerged in several cases due to the technological developments in relevant fields, the decrease in the cost of components, and the development of standards.
Product Concept & Definition	Not found to play a role
Project Planning	Not found to play a role
NPD process	Facilitator: During the 1960s, in two cases, production and testing enabled the commercialization process systems that had been developed by companies. Barrier: In the mid-1960s, there was a case in which the NPD process was not initiated because of the unwillingness of the company to invest further.

4.4.3. Interaction among Actors and Factors as Barriers and/or Facilitators

a) Interpret how actors interact within and across levels.

In line with the description of Table 4-6, several ways in which actors interact with each other can be derived. These are explained as follows:

- The role of actors can change in the course of the development of the technology*: Scientists that had a product vision and were willing to develop further their ideas founded Companies-Developers*.
- Actors license out proprietary technology to other actors: *Companies-Developers* acquired patents by *Scientists* or other *Companies-Developers* in order to develop and market a product based on them.
- Actors communicate market needs and potential solutions with each other: *Potential Users (Early Adopters)* or *Actors Representing an Industry* communicated market needs to *Scientists* or *Companies-Developers,* and thus potential applications of the technology were revealed.
- Actors leverage on resources of other actors*: Companies-Developers* allowed *Scientists* to undertake R&D activities by providing them with the necessary resources.

- Actors collaborate with other actors for production: *Potential Users (Early Adopters)* worked close with *Companies-Developers* in order to bring a product to the market.
- Actors are employed by other actors: *Consultants* were hired by *Companies-Developers* in order to evaluate the potential of a new technology.

b) Interpret how factors interact within and across levels by identifying mechanisms that work in favor or against development.

The following mechanisms of interaction among barriers and facilitators were identified:

Mechanism 1 - Barriers reinforce other barriers at another level: Operational problems related to the *Technology* and its applications meant that there were not any *Opportunities* for NPD projects. The lack of *Financial Resources also* hampered the initiation of the *NPD Process*.

Mechanism 2 – Facilitators reinforce facilitators at another level: Advances related to S*cientific Knowledge and Firm-specific Techniques* allowed the emergence of *Opportunities* for NPD projects. In addition, the decrease in the cost of lasers was an *Economic* factor that enhanced the emergence of market *Opportunities*.

Mechanism 3 – Barriers reinforce barriers within the same level: When the *Organizational Culture & Values* of a company entailed shortsightedness and risk-aversion, the result was a lack of investment by means of *Financial Resources*.

Mechanism 4 – Facilitators reinforce facilitators within the same level: The *Technological* progress in laser technology also meant that they were more affordable *Economically*.

Mechanism 5 – Facilitators diminish barriers within the same level: The *Technological* progress in laser technology increased the operational capabilities of the *Technology.*

c) Depict interactions among barriers and facilitators.

Figure 4-11 illustrates the aforementioned interactions among barriers and facilitators.

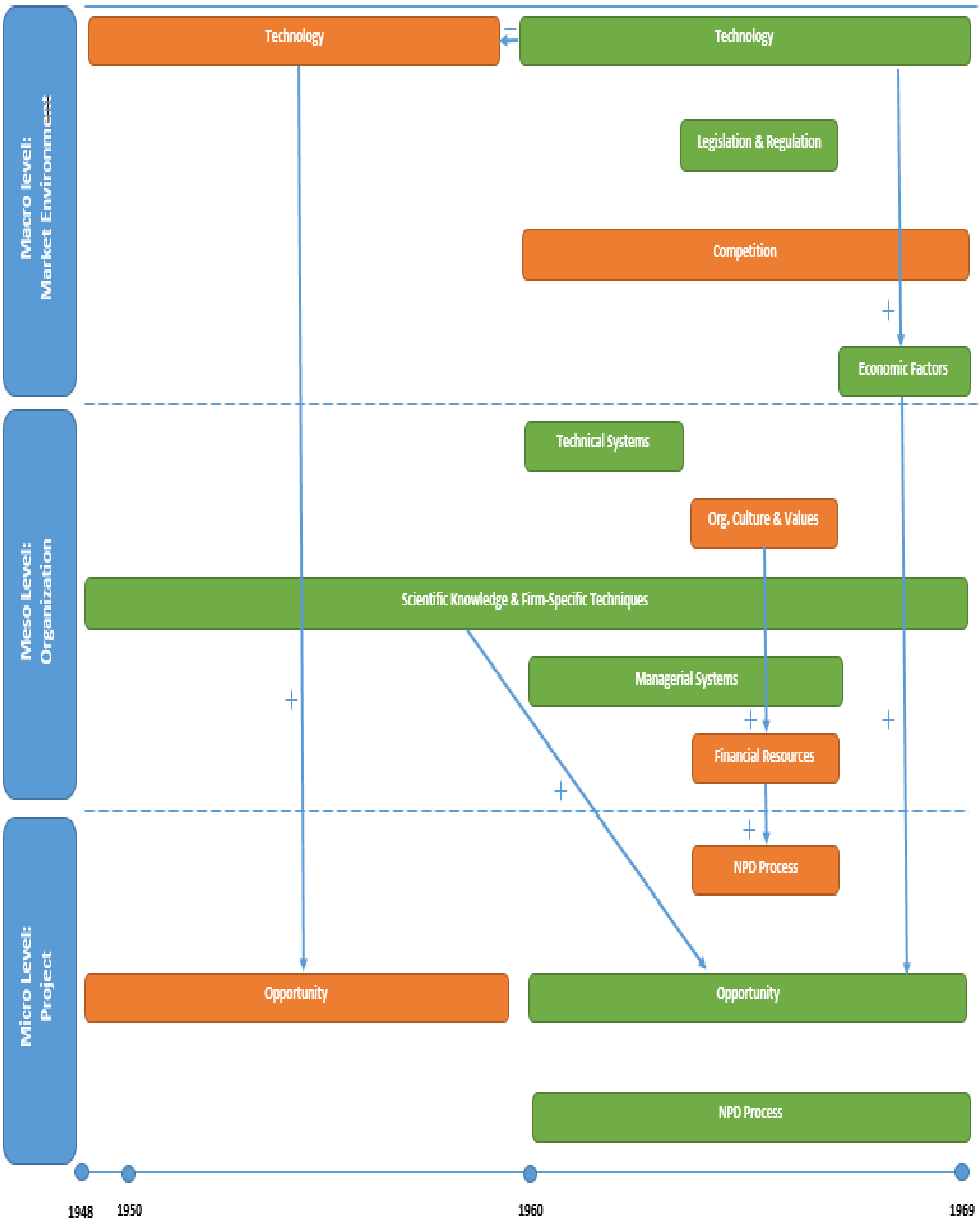

Figure 4-11 Interactions among barriers and facilitators for the barcode case

4.4.4. Conclusion

a) Determine the contribution of the results of the case study towards answering the research questions of the study.

1. What are the key actors and factors that either hamper or facilitate the development of the invention of a new high-tech principle into a marketable radical high-tech product?

The analysis of existing documentation revealed several actors that facilitated the development of barcode technology. These are the following:

Macro-level actors:

- Facilitator: Scientists
- Facilitator: Actors Representing an Industry
- Facilitator: Potential Users (Early Adopters)

Meso-level actors:

- Barrier/Facilitator: Companies – Developers
- Facilitator: Consultants

Regarding the factors that affected the development of barcode technology, these were the following:

Macro-level factors:

- Barrier/Facilitator: Technology
- Facilitator: Legislation & Regulation
- Facilitator: Economic Factors
- Barrier: Competition

Macro-level factors:

- Facilitator: Scientific Knowledge & Firm-Specific Techniques
- Facilitator: Technical Systems
- Facilitator: Managerial Systems
- Barrier: Organizational Culture & Values
- Barrier: Financial Resources

Micro-level factors:

- Barrier/Facilitator: Opportunity
- Barrier/Facilitator: NPD Process

2. How are these barriers and facilitators interrelated?

The actors were found to interrelate in the following ways (for specific examples see sub-section 4.4.3):

- The role of actors can change in the course of the development of the technology
- Actors license out proprietary technology to other actors
- Actors communicate market needs and potential solutions with each other
- Actors leverage on resources of other actors
- Actors collaborate with other actors for production
- Actors are employed by other actors

In addition, the following mechanisms between factors were identified (for specific examples see sub-section 4.4.3):

- Barriers reinforce other barriers at another level
- Facilitators reinforce facilitators at another level
- Barriers reinforce barriers within the same level
- Facilitators reinforce facilitators within the same level
- Facilitators diminish barriers within the same level

3. What strategies can be proposed to organizations seeking to introduce a radical high-tech product for the first time into the market?

In the case of barcode, established companies were active during most of the innovation phase. One example highlighted the case of a scientist that joined a company seeking to bring his idea in fruition. However, the company was either negative in developing a product or refused to buy his patent for a higher price. The patent was later sold to another company that aimed at commercialization till it was expired. This evidence suggests that *Strategic Patent Acquisition* (see RFID case) was also relevant to the barcode case.

In another case, a researcher came up with several product ideas when investigating within the company. However, the company refused to fund his idea based on a future promising application, as they sought to exploit only the current possibilities of the developed products. The researcher left the company to create his own, and successfully commercialize for the first barcode. On the contrary, the established company was left in the end with a “white elephant” (Seideman, 1993, n.p.), since the product that was being developed was not successfully commercialized. Based on the aforementioned facts, the following strategy can be derived:

Long-term investment in technology: Companies that are characterized by shortsightedness are less likely to innovate. Once a product has been developed, companies should continue to explore opportunities based on future applications of similar products. Often this will require patience in order to allow ideas to develop over time, as well as, commitment to ideas by further investments. This also means that companies should examine carefully ideas that are brought up by their employees or external individuals, which in the early phase might seem risky. If such long-term investment is lacking, creative scientists, engineers, or technologists, might decide to leave the company in order to develop their idea in another environment (e.g. a new venture that they will found, or another established company), where this is possible.

Finally, it is worth to mention that in the history of the barcode, there were cases where companies cooperated with potential users of the technology. For example, RCA developed a bullseye barcode system in collaboration with Kroger grocery chain. Furthermore, a barcode system for the railroad industry that was developed by Sylvania Corporation was tested for many years by Boston & Maine. The aforementioned facts indicate that *Working together with Potential Early Adopters* (see RFID case) can also be derived from the barcode case.

4.5. Cross-Case Analysis

4.5.1. Length of the Innovation Phase

Table 4-7 presents the length of the innovation phase for each case as defined by the identification of the respective hallmarks (i.e. H1 and H2). We can observe that the length of innovation phase was considerably long, which was also one of the criteria for selecting the cases originally. This allowed the researcher to observe several actors, factors, and interactions both within and across the three levels that were proposed by the theoretical framework of chapter 3.

Table 4-7 The innovation phase of case A and case B

Feature of the Innovation Phase	Case A RFID	Case B Barcode
H1 – Date of Invention	Mid-1940s	1948
H2 – Date of First Market Introduction	Late 1960s	1969
Length of the Innovation Phase (H1-H2)	About 25 years	21 years

Note that a major difficulty in defining the innovation phase of the two technologies was the interpretation of hallmark 1 (H1) and hallmark 2 (H2). For the RFID case, there was substantial agreement among the sources with regard to the first commercial use of RFID systems in the late 1960s, when the EAS systems were introduced. On the other hand, the date of the invention of RFID was disputable. For example, authors consider different demonstrations as the invention of the RFID: when the IFF systems were used for the first time in the mid-40s; when Stockman published his work “Communication by means of reflected power” in 1948; or when Cardullo patented a passive radio transponder with memory in 1969.

In this respect, the barcode case was different. While the sources agreed upon the date of the invention (i.e. the demonstration by Woodland and Silver in 1948-49), this was not the case for the date of the first market introduction. In particular, some authors consider the first commercial application of barcode systems was later in the 1970s (see Modgil et al., 2012).

4.5.2. Actors and Factors

Table 4-8 presents the actors that were visible in each of the cases. At the macro-level, only two actors were visible in both cases. These are: *Scientists* and *Potential Users (Early Adopters)*. Both of these factors facilitated the development of the technologies. At the meso-level, *Companies-Developers* were active during the innovation phase in both cases. Interestingly, for the case of RFID Companies-Developers acted both as a barrier and a facilitator. Another notable fact is the involvement of an external consultant that was hired by a company-developer. Unfortunately, the existing documentation was not sufficient to derive conclusions on more specific actors within the companies-developers, or actors at the micro-level, which is project-specific.

Table 4-8 Cross-case comparison of actors

Level of Actors	**Case A - RFID**		**Case B - Barcode**	
	Actor	**Function**	**Actor**	**Function**
Macro-level Actors	• Scientists • Autonomous Entrepreneurs • Potential Users (Early Adopters) • Government • Research Institutions	~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator**	• Scientists • Actors Representing an Industry • Potential Users (Early Adopters)	~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator** ~~Barrier~~/**Facilitator**
Meso-level Actors	• Companies – Developers	~~Barrier~~/**Facilitator**	• Companies – Developers • Consultants	**Barrier/Facilitator** ~~Barrier~~/**Facilitator**
Micro-level Actors	-		-	

One additional actor, which was not included in the initial list of actors, was identified to be relevant to the innovation phase:

- Consultants: In the case of barcode technology a consultant was active during the innovation phase. The consultant was hired by a company in order to evaluate the commercial potential of a patent that had been developed by an employee of the company. The consultant acknowledged the technology as promising. However, the company did not choose to invest in it because several years would be necessary before the patent could become marketable.

Table 4-9 presents the factors that were visible in each case according to the theoretical framework that was developed in chapter 3.

Table 4-9 Cross-case comparison of factors

Level of Factors	**Factors**	**Case A RFID**	**Case B Barcode**
Macro-level Factors	Technology	**Barrier/Facilitator**	**Barrier/Facilitator**
	Supply & Production (Networks)	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Infrastructure & Maintenance (Networks)	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Psychological & Cultural Factors	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Social Networks	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Environmental & Social Effects	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Government Policy	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Legislation & Regulation	**Barrier/Facilitator**	~~Barrier~~/**Facilitator**
	Economic Factors	**Barrier**/~~Facilitator~~	~~Barrier~~/**Facilitator**
Meso-level Factors	Scientific Knowledge & Firm-Specific Techniques	**Barrier/Facilitator**	~~Barrier~~/**Facilitator**
	Technical Systems	~~Barrier/Facilitator~~	~~Barrier~~ **/Facilitator**
	Managerial Systems	~~Barrier/Facilitator~~	**Barrier/**/~~Facilitator~~
	Organizational Culture & Values	~~Barrier/Facilitator~~	**Barrier**/~~Facilitator~~
	Financial Resources	~~Barrier/Facilitator~~	**Barrier**/~~Facilitator~~
Micro-level Factors	Opportunity	**Barrier/Facilitator**	**Barrier/Facilitator**
	Product Concept & Definition	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	Project Planning	~~Barrier/Facilitator~~	~~Barrier/Facilitator~~
	NPD process	~~Barrier/Facilitator~~	**Barrier/Facilitator**

Two additional macro-level factors, which were not included in the initial multi-level framework, were identified during the analysis of the cases. These are: *Institutional Risk* and *Competition*. Both of these factors functioned as barriers in achieving the first market introduction of the technology. Competition was identified in both cases, whereas institutional risk was identified only for RFID. What follows is an interpretation of the aforementioned factors according to their function.

- *Institutional Risk*

Although this factor is reported as a barrier to the commercialization of RFID technology, there is not enough information in order to draw a conclusion with regard to the specific way in which such a factor can either block or facilitate the development and diffusion of new technologies. It can be assumed that such a factor is related to the values that characterize the way market-level institutions manage potential future events-risks that affect their objectives as entities. A counterpart of corporate culture for firms. Further research should address the way in which institutional risk and its management affect the companies that seek commercialization of new technologies.

- *Competition*

Competition hampered the application of RFID concepts that had been developed and demonstrated as prototype. Here, competition refers to the development of alternative technologies by actors that are external to an organization, rather than to established or mature technologies that might also entail vested interests or a technological lock-in. In fact, for the application of RFID technology in the railroad industry, competition consisted of the barcode technology, which was also in its innovation phase. Barcodes were being tested by the railroad industry for several years, before the vision for the application of similar RFID technologies emerged. As for the case of the barcode, it is reported that midstream its innovation phase, other technologies that would provide the same function were being invented. Although there is no explicit reference about any adverse impact of these competitive efforts on the commercialization of the barcode, it is assumed that uncertainty with regard to competitors negatively affected projects related to the barcode.

4.5.3. Interaction among Actors and among Factors

Table 4-10 presents the different types of interactions that were visible in each case. The only similarity between the two cases concerns the fact that in both cases, Scientists or Autonomous- Entrepreneurs founded Companies Developers or licensed out patents to companies.

In sum, the following mechanisms became visible:

- *The role of actors can change in the course of the development of the technology*
- *Actors license out proprietary technology to other actors*
- *Actors communicate market needs and potential solutions with each other*
- *Actors leverage on resources of other actors*
- *Actors collaborate with other actors for production*
- *Actors are hired by other actors to evaluate technologies in terms of their market potential*

Table 4-10 Interactions between actors for each case

Interaction	Case A RFID	Case B Barcode
Companies-Developers were founded by Scientists or Autonomous Entrepreneurs	✓	✓
Scientists or Autonomous Entrepreneurs licensed out patents to Companies-Developers	✓	✓
Companies-Developers licensed out patents to Companies-Developers		✓
Potential Users (Early Adopters) communicated a market need to Scientists or Autonomous Entrepreneurs	✓	
Potential Users (Early Adopters) communicated a market need to Companies-Developers		✓
Scientists developed technologies within Research Institutes	✓	
Scientists developed technologies within Companies-Developers	✓	
Companies-Developers hired Consultants to evaluate patents by Scientists or Autonomous Entrepreneurs		✓
Companies-Developers developed a product in collaboration with Potential Users (Early Adopters)		✓

Concerning the interaction among factors, Table 4-11 presents the types of mechanisms were visible in each case. Everything included, interactions of factors both within and across levels were observed. More interestingly in one case only interactions across levels could be inferred.

Table 4-11 Mechanisms of interaction between factors

Category	Mechanism	Case A RFID	Case B Barcode
Within Levels	Barriers reinforced barriers		✓
	Facilitators reinforced facilitators		✓
	Barriers diminished facilitators		
	Facilitators diminished barriers		✓
Across Levels	Barriers reinforced barriers	✓	✓
	Facilitators reinforced facilitators	✓	
	Barriers diminished facilitators	✓	✓
	Facilitators diminished barriers		

4.5.4. Strategies

In total, four strategies were derived as a result of the case studies:

- *Collaboration with other Knowledge Producing Institutions*
- *Strategic Patent Acquisition*
- *Working together with Potential Early Adopters*
- *Long-term Investment in Technology*

The strategies *Collaboration with other Knowledge Producing Institutions* and *Strategic Patent Acquisition* emerged from the analysis of the RFID case. The barcode revealed the strategy *Long-term Investment in Technology,* but also supported the strategies: Working *together with Potential Early Adopters* and *Strategic Patent Acquisition*.

4.5.5. Discussion of the Results

What can be said about the generalizability of the results?

As previously mentioned in the methodological part of the case studies (see section 4.2), these two are illustrative and their results cannot be generalized to a larger population of radically new high-tech products. In order to derive more explanatory conclusions with increased external validity, a large heterogeneous set of technologies should be examined. This will allow not only to test in more depth the concepts that are proposed by this study, but also to account for contextual factors that might act as moderators. Here, I have tried to identify few potential contextual factors that might play a role in the emergence of actors, factors. These are: the type of technology (i.e. the general functionality of the technology); the historical period of development (i.e. the time period between invention and first market introduction); the type of the first commercial application (e.g. B2C, B2B or B2G); the sector of the first commercial application (e.g. transportation or manufacturing); or the existence of a non-commercial application prior to the first commercial application (e.g. if there is an application for military purposes).

In line with the previous analysis, as shown by Table 4-12, the cases of RFID and barcode have several commonalities and differences in terms of their context. On the one hand, their commonalities concern: the type of the technology; the time period of the invention and first market introduction; the type of first market application. Notably, despite the significant similarities between the cases of RFID and barcode their innovation phases involved also different actors, factors and interactions. On the other hand, their differences concern: the sector of the first market application; and the existence of a prior non-commercial application of the technological principle. However, no conclusions could be derived on how such contextual factors might have affected the results of the case studies.

Table 4-12 Contextual factors that might affected the results

Contextual Factor	Case A RFID	Case B Barcode
Type of Technology	AIDC	AIDC
Historical Period of Development	Mid 1940s - Late 1960s	1948 - 1969
Type of (First) Commercial Application	B2B	B2B
Sector of (First) Commercial Application	Retail/Security	Manufacturing/Logistics
Prior Non-commercial Application	Yes: Military Spin-off	No

What are the theoretical implications of the results?

Overall, the results can be considered encouraging since they supported the emergence of a wide variety of actors, factors, and interactions during the innovation phase. The case studies also supported the theoretical framework that was developed in chapter 3, in that both interactions within and across levels could be identified. Furthermore, two new factors that had not been included in the initial framework were identified: *Competition* and *Institutional Risk*. As a next step, further research is required to discover other types of interactions within or across levels.

On the other hand, a major limitation of the theoretical framework (see chapter 3) concerns the theoretical assumptions based on which it was constructed (see chapter 2). In particular, the theories that were selected in order to derive barriers and facilitators from an organizational perspective concern mostly innovation that takes place within established firms. Yet, a significant part of the innovation phase is mostly characterized by R&D activities undertaken by individuals or other public or private R&D institutes. This was especially the case of RFID; in which it was only later in the innovation phase that the aforementioned actors formed companies or that they acquired technologies that had been developed by them. Thus, a more suitable approach to study the innovation phase should consider factors that either hamper or facilitate the R&D efforts of scientists, individual entrepreneurs, and other private or public R&D institutions beyond companies.

What is more, the investigation of the cases can be related to the study of Ortt and Schoormans (2004), who introduced the concept of the innovation phase within the pattern of development and diffusion of breakthrough technologies. In line with their analysis, the case of RFID showed that different estimations of the length of the innovation phase can be derived, depending on the definition of the invention hallmark. In turn, the definition of the invention might also affect the selection of the date of the first market introduction, although for the latter the sources related to RFID were more congruent. On the contrary, in the case of the barcode, while there was considerable agreement on the date of the invention, interpretations of the date of first market introduction varied. This suggests a need for an explicit definition of the generic product, whose investigation is attempted. Further research seeking to address the innovation phase of other technologies should take into account the latter suggestion.

Finally, the length of the innovation phases of RFID and barcode can be considered as long when comparing the results of the two case studies with the work of Ortt (2010). After studying several technologies belonging to different industries, Ortt estimated that the average length of innovation phase amounts to 10 years with a corresponding standard deviation of 13,5 years. Here, the length of the innovation phase for the RFID and barcode technologies were found to be about 25 years and 21 years respectively.

What are the managerial implications of the results?

At first glance, the long duration of the innovation phase suggests that firms seeking to commercialize their new high-tech products have to invest a lot, for a long period of time, without expecting any source of income. However, a more rigorous consideration of the two cases indicates that this need not always be true. Timing matters. The analysis of the cases suggests that the innovation phase is characterized by significant dynamics in terms of the actors involved with research and/or NPD projects. Actors might “enter” or “leave” the innovation phase at any point in time, because of several factors.

Indeed, considerable long-term investment might be required by companies seeking to survive the innovation phase. At the same time the level of return on investment is highly uncertain before diffusion starts (i.e. before the next phases of development and commercialization). This is also logically expected, if we assume that the main characteristic of high-tech markets is uncertainty (Mohr et al., 2009). Uncertainty can concern the technology, the customers, the suppliers, etc. In the cases of RFID and the barcode, companies were engaged with innovation related activities for many years, without very “promising” indications of “rewarding income” anytime soon. Interestingly, there were companies that never saw profits from the products they had been developing for many years (e.g. the barcode-based system developed by Sylvania for the railroad industry that was being tested since 1961, or the RFID counterparts that were developed in the late 1960s- early 1970s, while the first market application of RFID in transportation was realized in 1987 for automated toll collection systems).

Why did these companies never see profits from their products? Based on the facts, there are two explanations. The first explanation is that these products concerned complex technologies aimed at systemic applications and large-scale diffusion. These technologies might initially have been cumbersome or expensive, and industries were clearly not ready to adopt them. The second explanation is that large-scale diffusion might be more susceptible to adverse macro-developments. For example, when the aforementioned barcode technology was ready for takeoff in the early 1970s, the economic crisis hit the railroad industry, and thus the technology was abandoned.

On the other hand, the history of RFID and barcode reveals that in some cases, companies were able to commercialize their products in only a few years with relative success. See for example, the RFID-based EAS systems, which were commercialized by Knogo, Sensormatic and Checkpoint in the late 1960s, while the first two were founded after 1965. Or in the case of Computer Identics that was founded in 1967 and by 1969 had managed the commercialization of its products.

How did these companies manage to bring their products to the market, especially when they were new ventures, probably barren of resources, compared to existing companies? Again, based on the facts there are two possible explanations. The first explanation suggests that these companies developed and marketed “simple” technologies, for which customers were individual businesses and not large industries. The second explanation is that: timing matters. Both the RFID-based EAS systems and the barcode-based product of Identics, were facilitated by macro-technological developments in other fields. For example, in the late 1960s the transistor that was about to be used in the EAS systems was becoming better and cheaper. Similarly, during the same period lasers that were used in the barcode systems of Identics were becoming better and cheaper.

The aforementioned stories of “failure” and “success” show that it is not always a matter of a long period of investment. Timing also matters. Note, that the different explanations of why companies failed or succeeded, are not competing. In fact, in many cases it is the dynamic combination of factors in different spheres that determine success. While factors that have been already identified, such as the perceived macro-developments that affect an industry (e.g. technological, economic or political developments), often play an important role, the context also matters. The context might refer to the type of application (i.e. more systemic or less systemic), or the degree of complexity of the high-tech product (i.e. relatively simple or complex systems). Managers of technology should devise appropriate strategies by additionally taking into account these contextual factors.

4.6. Conclusion

This chapter investigated two historical cases of radically new-high tech products. The framework that was developed in chapter 3 was applied and several of its limitations were revealed. At the same time, the framework was enriched with the identification of factors that had not been regarded by the theoretical literature review of chapter 2. Among the results were also the estimation of the length of the innovation phase, and the identification of possible strategies within the innovation phase. The findings also had managerial implications that could possibly enlighten innovation practices.

5.Conclusion and Discussion

This study attempted to explore the innovation phase of radically-new high tech products. The innovation phase comprises the period that spans from invention to the (first) market introduction. Previous observations related to the increased length of this period and the significant failure rates of innovations served as a motive to explore the landscape on which firms and other actors operate. The questions that were posed were as follows:

1. *What are the key actors and factors that either hamper or facilitate the development of the invention of a new high-tech principle into a marketable radical high-tech product?*
2. *How are these barriers and facilitators interrelated?*
3. *What strategies can be proposed to organizations seeking to introduce a radical high-tech product for the first time into the market?*

In order to answer the research questions, two research methods were employed: a theoretical literature review, and two case studies. The theoretical literature review revealed knowledge gaps with respect to the second research question. Based on the assumptions of existing literature, a theoretical framework was proposed in order to address the issue. The theoretical framework that was proposed serves both as a static list of influencing factors and to address interrelations among them. The framework was illustrated and refined by examining two historical case studies of radically-new high-tech products. As regards the third research question, strategies that are relevant to the innovation phase were derived as a result of empirical observations within the case studies.

5.1. Answers to the Research Questions

What are the key actors and factors that either hamper or facilitate the development of the invention of a new high-tech principle into a marketable radical high-tech product?

The innovation phase is characterized by significant dynamics in terms of the emergence of actors and factors. The same actors and factors can act as barriers or facilitators to the innovation process. This study argued that these actors and factors can be better understood if categorized into three distinctive but closely interconnected levels. The macro-level, consists of the market-environment, where a wide variety of both technological and social actors and factors that are external to the innovative organization might influence its development efforts. The meso-level comprises the organization or the network of organizations that innovate. The organizations are represented by their management, structure and different type of resources that guide their perceptions of the market-environment, and thus the selection of R&D and NPD projects. Finally, the micro-level is composed of the projects that are responsible for bringing new products to the market. Here, actors and factors are determined by their role and function in the NPD process.

The actors and factors that have been identified as a result of both the literature review and the case studies are presented by Table 5-1. It is important to note that the actors and factors should be treated as broader elements that encompass various aspects. Put differently, they are not only categorized into levels but also within levels. Categorization within levels aims at increasing the completeness in terms of the actors and factors at each level. This is important because technological innovation takes place within various contexts. Specific actors and factors might vary significantly depending on the type of industry or the type of technology. Thus, attempts to derive a more detailed list of actors and factors for a great deal of industries and products would limit significantly any theoretical value.

Table 5-1 Factors that affect the innovation phase of radically-new high tech products

Factors	Actors
Macro-Level	
• Technological Factors • Economic Factors • Competition • Supply Networks • Infrastructure & Maintenance Networks • Social Networks • Psychological & Cultural Factors • Social & Environmental Effects • Government Policy • Legislation & Regulation (Laws, Standards and Rules) • Institutional Risk • Competition	• Governments • Research Institutes • Universities • Industries • Policy-makers • Regulators • Suppliers • Providers of complementary products • Potential Users (Early Adopters) • Scientists • Autonomous Entrepreneurs
Meso-Level	
• Scientific Knowledge and Firm-Specific Techniques • Technical Systems • Managerial Systems • Organizational Culture and Values • Financial Resources	• (Network of) Companies-Developers • Top- management • Executives • Consultants
Micro-Level	
• Opportunity • Product Concept & Definition • Project Planning • NPD process	• Project Manager • Project Team • Product Champions

How are these barriers and facilitators interrelated?

Actors and factors should not be treated independently. Interrelations among actors and factors take place both within and across levels. Concerning the factors, the following pattern emerged: a factor can reinforce or diminish another factor. In line with this conceptualization, a variety of mechanisms of interaction could be identified. A basic typology of interactions can be derived by distinguishing eight simple mechanisms (see Table 5-2), six of which were also supported by the case studies (see sub-sections 4.4.3 and 4.5.3 for specific examples of how these interactions work). There is no systematic reason for which two of these mechanisms were not identified. Instead, the latter is a result of case-specific events. As already shown using specific examples (see subsections 3.2 and 3.4), all of these eight basic mechanisms can possibly arise. Further case studies are expected to confirm such observation.

Table 5-2 Typology of basic mechanisms

Category	Mechanism
Within Levels	A barrier reinforces another barrier
	A facilitator reinforces another facilitator
	A barrier diminishes a facilitator
	A facilitator diminishes a barrier
Across Levels	A barrier reinforces another barrier
	A facilitator reinforces another facilitator
	A barrier diminishes a facilitator
	A facilitator diminishes a barrier

Interestingly, the aforementioned description suggests that more advanced mechanisms of interaction can possibly emerge. Examples of such mechanisms are the following:

- Facilitators may diminish barriers at different levels simultaneously
- A combination of facilitators maybe required in order to diminish some barriers
- A chain of reinforcing barriers might create a negative feedback loop

What regards the interactions among actors, a uniform categorization was not possible. The nature of such interactions is more complex. Actors might collaborate, compete, exchange different types of resources (e.g. technology in exchange for financial resources, or financial resources in exchange for research etc.) etc. The case studies revealed the following patterns:

- The role of actors can change in the course of the development of the technology
- Actors license out proprietary technology to other actors
- Actors communicate market needs and potential solutions with each other
- Actors leverage on resources of other actors
- Actors collaborate with other actors for production
- Actors are employed or hired by other actors

What strategies can be proposed to organizations seeking to introduce a radical high-tech product for the first time into the market?

The following generic strategies were found to apply to the innovation phase:

- *Collaboration with other Knowledge Producing Institutions* – Knowledge and research institutes such as universities or national labs can be central during the innovation phase. This is because they both pursue related research activities and develop a wide range of technological innovations. Organizations that collaborate with them are more likely to benefit from developments in knowledge, basic technologies, and human capital.

- *Strategic Patent Acquisition* – The innovation phase might involve many inventions related to a new technology. Most of the time these inventions will be patented in order to provide protection and strengthen the position of early innovators against competition. Firms are advised to develop knowledge of: *(a)* the specific conditions under which the acquisition of patents results in successful early market introduction; and (b) the criteria based on which individual entrepreneurs or scientists opt out between the foundation of a new company and licensing out their patents to established companies.

- *Working together with Potential Early Adopters* – Development of knowledge about the application of new technologies is critical for their commercialization, which is the overall goal of the innovation phase. The involvement of potential early adopters can assist this process, for example, by communicating market needs, providing input about user requirements, or testing the product in real-world conditions. Such activities can result in: the identification of opportunities for development, improvements in the design and performance, or indicating the market viability of a new product.

- *Long-term Investment in Technology* – Radically-new high-tech product concepts might appear as very risky options for organizations, since a lot of time might be required in order for them to gain in commercial value. The exploration of further potential applications of a high-tech product that is being developed might be crucial in order to bring it to the market. In turn, this should be allowed by a long-term commitment to the technology.

The aforementioned four strategies are not competing alternatives, rather, they should be viewed as mutually supporting options for firms seeking to commercialize a radically-new high-tech product.

5.2. A Note on the Completeness of the Mechanisms of Interaction

Among the findings of this paper that were presented in the previous section is the identification of a set of mechanisms of interaction among factors or actors. An interesting inquiry logically following such a conclusion concerns the completeness of these mechanisms: Is this set of mechanisms complete? Until this point, this paper has argued for the completeness of the set of mechanisms by means of: (i) the inclusion of the three levels distinguished (i.e. market environment, organization, and project), and (ii) the identification of interactions both within and across these levels. However, another critical aspect is whether these mechanisms sufficiently reflect the key activities that take place during the innovation phase?

In order to assess the aforementioned aspect, I consider the functions of Innovation Systems (IS), as described by Hekkert et al. (2007). Their study proposed that the following key processes are vital for a well-functioning IS: (1) entrepreneurial activities, (2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of search, (5) market formation, (6) resources mobilization, and (7) creation of legitimacy/counteract resistance to change. Thus, it would be interesting to see how these functions can be formulated by means of interactions between factors that have been identified by this paper. In order to illustrate the latter, the following examples per function are provided:

- **Entrepreneurial activities** – Entrepreneurial activities are likely to intensify when *technological or economic factors* (e.g. progress in a general purpose technology or decrease in its cost) affect positively the emergence of new business *opportunities* worth exploring (e.g. a new product that will likely have an increased performance or become more affordable because of its operation is based on the general purpose technology).

- **Knowledge development –** Knowledge development is enhanced by learning by searching and learning by doing. For example, both *project planning* activities for a new product and the *NPD process* itself might result in novel *scientific knowledge or firm specific techniques, technical systems, or managerial systems.*

- **Knowledge diffusion through networks –** Knowledge diffusion is enhanced through the emergence of networks. For example, s*upply networks*, as well as, *infrastructure and maintenance networks* are not only useful for developing or commercializing a new product, but result in acquiring knowledge through collaborations. As in the case of knowledge development, such knowledge can take the form of *scientific knowledge or firm specific techniques, technical systems, or managerial systems.*

- **Guidance of search –** Guidance of the search might be performed for example by a specific *government policy* that gives rise to new business *opportunities*.

- **Market formation –** Market formation should be seen as an overall goal during the innovation phase. Although no diffusion takes place during the innovation phase, the vision about market formation plays an important role during the innovation phase. For example, new *government policies*, or the introduction of *legislations or regulations* that affect a technology, might be perceived as signs to explore new market *opportunities* and initiate an *NPD process*.

- **Resources mobilization –** Resources mobilization might become more intensive, when, for example a new *government policy* is responsible for the availability of *financial resources* for firms in order to invest in R&D and thus explore *opportunities* for new products. In another example, resources mobilization takes place when supply networks are responsible for firms exchanging human or other types of capital in order to develop new capabilities in the form of *scientific knowledge and firm-specific techniques*, or *technical systems*.

- **Creation of legitimacy/Counteract resistance to change –** Creation of legitimacy is enabled for example when the availability of *financial resources* allows companies to promote new technological solutions to other market actors as *opportunities* worth exploring (e.g. by presenting new product concepts to market regulators) or perform any other type of lobbying activities. In turn, this might result in a new *government policy* (e.g. a tax exemption) that will also help actors deal with opposition stemming from *competition* or other vested interests.

The aforementioned examples showed how the functions of IS can be formulated as interactions between factors that either hamper or facilitate the innovation process, as identified by this paper. Possibly, many more examples of interactions can be derived. Note that the interactions that were previously presented take place both within and across the levels that have been distinguished (i.e. macro, meso and micro-level). What is more, they concern mostly interactions that are positive for innovation (i.e. explain why does a function of an IS take place): facilitators that reinforce other facilitators (e.g. government policy increases the availability of financial resources) or facilitators that diminish the effect of barriers (e.g. government policy diminishes the adverse effect of competition). However, in a similar way the reason for which a function of an IS does not advance can be explained in terms of other mechanisms of interaction (i.e. when a barrier reinforces other barriers or diminishes the effects of facilitators).

Noteworthy, is also the fact that the categorization of actors and possible interactions among them is also relevant in order to explain the functions of IS. For example, a macro-level actor (e.g. the *government*) might be responsible for making funds available for a meso-level actor (e.g. a *company developer*). In turn, an interaction between actors (e.g. "*actors leverage on resources of other actors*") can explain a function of an IS (e.g. in this case: resources mobilization). Again, as in the case of factors, actors may belong to different levels and interactions both within and across levels can occur.

5.3. Theoretical Relevance

By attempting to shed light on the innovation phase of radically-new high-tech products, this study opened a new field for research. Despite the vast literature on Technological Innovation and New Product Development, a picture of the landscape with which organizations are confronted during this period was still unknown. In pursuance of understanding the innovation phase, it has been proposed that concepts discussed by different theories should be synthesized. By solely focusing on theories, a comprehensive account of the key actors and factors that are relevant to innovation phase is highly unlikely. From a wider perspective, innovation takes place at different levels at which the actors and factors involved differ considerably. More importantly, both the goals of actors and the nature of factors that affect the outcome of innovation also diverge. This means that theory is in need of more holistic approaches to innovation in order to explain phenomena related to the pre-diffusion period of innovation, such as the significant variation in the length of the pre-diffusion phases as discussed by Ortt (2010).

This study distinguished between three broad levels at which innovation comes about: the market-environment; the organization; and the project level. Each level comprised of elements that were discussed by different theories: the construction of the market environment was enabled by concepts considered by the SNM theory; the organization was discussed according to concepts based on both the theory of the organizational capabilities and the VoD theory; and the project consisted of the concepts discussed by the FFE theory. As a first step, the multi-level conceptualization allowed the identification of key actors and factors that are relevant for each level. This was enabled by the existing literature. However, the main contribution of this study concerns the proposition of possible interactions that take place both within and across levels. Such interactions can better explain variation and selection mechanisms that drive socio-technical change.

In addition, the findings of this paper relate to previous studies on innovation. Firstly, the results are relevant to the VoD theory (see Markham et al., 2010). Although, the VoD theory emphasizes the lack of financial resources as the key barrier to innovation, this study found that other factors that are suggested by the theory on organizational capabilities (Leonard-Barton, 1992) might be more relevant. Such factors, can be broadly distinguished into: scientific knowledge and firm-specific techniques; technical systems; managerial systems; and organizational culture.

Secondly, the results of the study add to the FFE theory. In particular, the study of Zhang and Doll (2001) suggested that certain types of uncertainty might negatively affect the FFE of innovation. Such uncertainty relates to the customer, the technology, and the competitors. Despite the relevant completeness of such categorization, this study revealed other types of factors that could possibly entail uncertainty for NPD projects, such as institutional risk, or legislation and regulation. Thus, further discussion is required with regards to the causes of the "fuzziness" that pertains to the early stages of innovation projects.

Finally, we can relate the propositions of this study to the work of Ortt et al. (2013) who proposed factors that affect the market adaptation phase of the pattern of development and diffusion of new high-tech products (see section 1.3). Such factors affect large-scale diffusion of innovations that signifies the initiation of the market stabilization period. Although these factors are not directly comparable to the factors identified by this study since they are categorized in a different manner, we can observe that there are significant similarities between the findings of the two studies. For example, the *new high-tech product* (which is related the outcome of the *NPD process)*, the *availability of customers* (i.e. the potential users - early adopters), the *institutional rules* (i.e. *legislation and regulation*), the *knowledge of technology and application* (which are related to the *scientific knowledge and firm specific techniques, technical systems, managerial systems, project planning, and the potential early adopters*) or social and *cultural aspects* (which are directly related to *social and environmental effects,* and *cultural and psychological factors*). In short, many of the factors that are relevant for the market adaptation phase (i.e. because the block large-scale diffusion) can be expressed directly by factors or actors identified by this study or by synthesizing them (e.g. by looking at their combined effect or their interrelations).

A preliminary explanation for the observation is that the emergence of the market adaptation phase is only one possible scenario for the pattern of development and diffusion of high-tech products (Ortt, 2010). Thus, if the innovation phase is followed by the market stabilization phase (i.e. the market adaptation phase is non-existent), then the first market introduction would also signify large-scale diffusion, and thus the factors by Ortt et al. (2013) would also apply to the innovation phase. A second explanation stems from the logical belief that some core factors such as the availability of customers, the knowledge of the technology might enhance or block diffusion irrespective of the level of adoption (i.e. no matter if we talk about niche markets or large-scale diffusion).

On the other hand, when comparing in more detail the factors that affect the market adaptation phase and those that affect the innovation phase, notable differences between them become visible. Firstly, factors such as the *opportunity,* the *project planning*, *and managerial systems* are missing in the model developed by Ortt et al. (2013). Such differences arise from the fact that the factors of their study were derived from a macro-level theory. This study has further introduced the meso and micro-level of analysis by adding further theoretical perspectives that focus more on the organization and the specific project within which a new product is being developed.

Secondly, the factors *accidents/events* and *natural resources* that have been discussed by Ortt et al. (2013), were not addressed by this study since they were neither identified by the literature review, nor did they appear in the case studies. Thus examples of how these factors apply to the innovation phase are still to be found by further empirical studies.

Thirdly, although many factors are seemingly similar, the way in which they affect the market adaptation and the innovation phase might substantially differ. This is the case for the *production system* for a new high-tech product. Ortt et al. (2013) had stressed the fact that when "industrial production technologies are not yet available" (p. 4), then large-scale diffusion is blocked and we can expect the emergence of niche markets and possibly a longer market adaptation period. However, this does not necessarily apply to the innovation phase, where the need for such a technologically "mature" production system is absent. This was also visible in the barcode case where the first commercial application included handmade components. Similarly, *institutional aspects* might have different effects on the innovation phase compared to the market adaptation phase. For example, when RFID and the barcode were commercialized for the first time, an industry standard was missing.

The aforementioned remarks confirm Ortt and Schoormans' (2004) model, which distinguished between the innovation and the market adaptation phase. Similar factors might behave differently depending on the phase of development and diffusion, within which a new high-tech product is positioned. This means that strategies to cope with each phase are also expected to be different. Future research should further examine in more detail the differences between the innovation and market adaptation phase in terms of the actors, factors, and strategies that could be applicable.

5.4. Practical Relevance

The innovation phase of radically new high tech products is characterized by increased dynamics in terms the barriers and facilitators involved. Various actors and factors can dynamically initiate, enter, or abandon R&D or NPD projects at any point in time. The role of the actors and factors, as well as the interrelationships between them can also change in time. Such a scene entails increased uncertainty for the actors seeking to develop and commercialize new technologies. Practitioners are advised to adopt an overall systems perspective in order to assess the current state barriers and facilitators to innovation, as well as to develop a vision about related future developments. Unfortunately, there is no panacea for the challenges faced by actors during the innovation phase. Solutions must be tailored to the specific context with which development and commercialization efforts are confronted. The generic strategies proposed by this study (see sub-section 4.5.4) can be used as areas of focus for practitioners, who should adapt them to their specific case.

The multi-level framework that has been proposed by this study aims to provide companies with a better understanding of the innovation phase of new high-tech products. By applying the framework, companies can analyze their specific context by: (i) identifying the key actors and factors that can possibly affect the outcome of innovation, based on the categorization proposed; (ii) evaluating their function as barriers and/or facilitators, based on manifestations that suit their context; (iii) addressing interrelationships between actors and factors using a similar typology as the one by this study. Furthermore, the framework provides multiple-starting points in order to derive strategies appropriate to the context that has already been analyzed. Suitable strategies should be derived based on the exploitation of facilitators and the reduction of barriers at different levels. These should aim to achieve the right balance between the dynamics of environmental forces and internal structures, resources, processes and roles.

Interestingly, the two case studies revealed aspects of the innovation phase of AIDC products that have further practical implications. On the one hand, the fact that the innovation phase might last for many years or even decades means that companies possibly need considerable funds for a long period of time in order to develop and market a new high-tech product. On the other hand, this is not always true, since the timing, the type of application, and the degree of complexity of the product also matter. What is meant by timing is the position of companies within the innovation phase. Such a position, might play an important role for commercializing quickly a new product since companies might emerge or start developing a new product at the "late" innovation phase. For example, the first market introduction of the barcode was pursued by a company that had been founded only two years before this time. This first application of the barcode took advantage of developments in laser technology, that had recently increased in performance and affordability. Similar was the case of RFID (see sub-section 4.3). Moreover, the first market introductions of both RFID and the barcode concerned rather simple products, and businesses as early adopters. Other earlier visions about the commercialization of more complex products with industries as clients were late for their first market introduction.

5.5. Reflection on Methodological Approach

Following the previous discussion, it would be remiss not to mention the limitations of the research design that potentially influence the interpretation of the findings of this study (both *a priori* and *posteriori*). To begin with, it is important to reflect on the choice of theories that were examined in order to derive an appropriate conceptual model. This paper has previously argued (see sub-section 2.2.1) for a theoretical literature review that selectively examines different sub-fields of innovation literature in order to address the theoretical aspects of the research issues. The basic criterion for the selection of these theories was their relevance for addressing innovation before diffusion takes place. The aim was to integrate concepts from these theories to Ortt and Schoormans' (2004) model, and particularly to what they identified as the innovation phase of breakthrough technologies. Indeed, the theories that were examined proved relevant to the innovation phase, especially since they concern ways in which to bring innovations to the market. However, a synthesis of these theories neglects the particular context from which they originate. These theories do not exclusively consider “radically-new high-tech products”. Some theories discuss innovation within a more general context (e.g. Trott (2011)), and others focus on specific settings (e.g. SNM theory focuses more on sustainable transitions and systemic technologies). Future research should focus further on discussing the role of each of the following concepts in depth: “high-tech”, “product”, and “radical”. This study has provided a solid base by synthesizing the theories that were considered the most suitable for the research questions. Prior to this study, a theoretical basis to address the research problem was missing.

Moreover, the selective literature review methodology in order to identify actors and factors incorporated: (i) criteria to include or exclude sub-fields of literature and the corresponding representative studies that could be criticized as subjective; and (ii) a search strategy that did not involve a formal quality appraisal process; thus the selection of studies was also vulnerable to subjectivity. Further objectivity should be achieved by demonstrating the aforementioned methodological aspects. Reviewing more articles from each sub-fields of literature can possibly reveal more actors and factors that play a role in the innovation phase. This would mean attempting a literature review for each theoretical field that has been discussed by this study. Additionally, further sub-fields that mainly focus on each level of the framework that has been presented can be studied. As in the previous case, this would improve the objectivity with regard to the identification of actors and factors, further theoretical perspectives will be represented. More specific propositions about literature that could be examined are provided later in sub-section 5.6.

It is also noteworthy that the selection of theories that are relevant to the innovation phase proved incomplete in certain ways. In particular, the case studies showed that innovation is significantly influenced by individuals both outside and within firms and other institutions. However, the theories taken into account by this study do not focus on the role of the individual within an organization or different barriers and facilitators might apply to autonomous entrepreneurs willing to develop a new high-tech product. Further research can address the relevance between such theories of entrepreneurship and the innovation phase. In addition, although previous studies have managed to distinguish specific roles of individuals within organizations (e.g. champions) (Markham et al., 2010), the examination of historical secondary data did not allow to distinguish such actors. Interviews within innovative companies might be able to distinguish the importance of such roles for the innovation phase.

Other limitations of the research design stem directly from the empirical approach of the study. Several weaknesses were identified whilst examining the historical cases; both before and during the analysis of secondary data. Firstly, if a specific actor or factor that was included in the theoretical framework was not mentioned in existing documentation, then it was considered to be non-significant. However, such assumption entails considerable bias resulting from the historical description of other authors. Secondly, after the primary search for data in scientific database, it was realized that there was inadequate evidence to define the pattern of development and diffusion for the selected cases, as well as interpret the function of identified actors and factors. In order to come up with sufficient information, the secondary searches that were executed, resulted in data of lower reliability. Thirdly, the data limitations with regards to project level actors of innovations was particularly challenging to the application and illustration of the theoretical framework. Specific actors within the project level could not be identified. Lastly, the analysis of the innovation phase through case studies is characterized by a bias for successfully commercialized innovations. However, there are products that never make it to the market. Thus, conclusions about the length of the innovation phase or the completeness of factors that hamper innovation might be limited.

Finally, as part of the reflection to the methodological approach of this study, there is also a need to discuss aspects of the research design of this study that should be taken into account by future studies that will have a more explanatory approach towards the research issues. The following points can be useful for further studies that might attempt to test the robustness and objectivity of the findings of this study or attempt to better explain them:

- *Construct validity* should be empowered by narrowly defining the specific actors and factors identified, and the relationships between them (see sections 1.7, 2.4, and 3.4). In this study, these concepts are rather broadly defined. In particular, the barriers and facilitators can be thought as categories of more specific variables (e.g. the factor "NPD process" includes concepts such as: manufacturing, prototyping, and testing). These more specific variables should be examined more systematically in order to be able to provide a robust way of "measuring" actors and factors within historical data. Additionally, there is a need to secure that there will be no overlap between the content of actors and factors. For example, the current categorization might entail an "overlap" between the factors "government policy" and "legislation and regulation", since the provision subsidies is assisted by the introduction of regulations or laws. By securing that the definitions of actors and factors do not overlap, the identification of interrelationships will increase in objectivity. The process of producing a list of more specific actors and factors, and diminishing overlaps among them, can be assisted by interviewing a panel of experts in order to minimize researcher bias.

- *Internal validity* should be examined with respect to the casual relationships (reinforcing or diminishing) between factors (i.e. barriers and facilitators). This aspect is also related to the previous point. By providing more detailed definitions and specific measures to operationalize the actors and factors, correlation among factors can be diminished, and thus, causation can be better understood. Moreover, the exact time sequence of the factors that are identified in the cases can also enhance the establishment of causal relationships among factors. Specifically, finding "strong" evidence of the exact time sequence in which barriers and facilitators emerged will be crucial.

- *External validity* should be aimed by replication. Here, only two cases of a specific category of products are examined. However, this does not allow conclusive generalizations about the grater population of radical high-tech products. The examination of an extensive sample of radically-new high-tech products can further test the generalizability of the findings of this study. This will also assist in deriving conclusions about potential differences among the innovation phases of different industries or markets.

- *Reliability* should be addressed by thorough record keeping of historical data that will be analyzed by future studies (e.g. see Appendices A and B of this paper), and by exhibiting a clear decision path that is used for collecting and analyzing data (e.g. see section 4.2.4). Such process will increase the transparency and consistency with regards to the identification of actors and factors, their interpretation as barriers and facilitators, and the explanation of positive or negative interrelationships among them. In addition, researcher bias can be decreased by engaging a group of other researchers in the case study process.

5.6. Recommendations for Further Research

This study proposed a conceptual framework useful to address key actors, factors, and interrelations that affect innovation. The framework was applied to two case studies in order to illustrate its usefulness. Clearly, further research will be needed to validate the framework and increase its completeness. An examination of a broad heterogeneous sample of other high-tech products is required to prove its practicality and test its applicability in other contexts. Here, the framework was applied only to two cases of AIDC technologies whose innovation phase covered a specific period in time. The examination of a larger set of cases should test the existence differences between different types of products and periods of development. Such work will enable both the revision of the framework that has been proposed here, and the suggestion of strategies other than those proposed by this project.

What is more, a continued theoretical discussion of the innovation phase would also be justified as this thesis focused selectively on theories relating to the questions at hand. Further study on how other theories on the topic differently interpret the innovation phase (e.g. by presenting an overview and/or a comparative analysis) would be desirable in order to expand our knowledge of the innovation phase. Specifically, in order to gain more insight into macro-level actors and factors that apply to the innovation phase, one could examine what factors and factors can be derived from the theory on Sectoral Systems of Innovation or Technological Systems of Innovation and compare these perspectives with the SNM perspective. Similarly, for the meso-level, one could compare the knowledge-based view of the core capabilities of organizations with a resource-based view by looking into relevant theories. Finally, with regard to the micro-level, someone one could look into Technological Readiness Level models and compare them to theories that focus on the FFE of NPD development, or to the stage-gate models for the management of NPD processes. The aforementioned process would not only provide a more systematic way of seeking out similarities and differences across theories that relate to the innovation phase, but it would also ensure that different theoretical perspectives are represented when addressing the research issues that have been discussed by this study.

At the same time, several other questions about the innovation phase remain to be answered. For example, although this research recognized the existence of more advanced mechanisms of interaction among factors, these mechanisms could not be identified through the case studies. Hence, future case studies should explore how these more advanced mechanisms of interaction among factors. In addition, this research did not interrelate the actors and the factors with each other. Thus, further research should consider possible interrelations between actors and factors by building on the list of actors and factors presented by this study. Such an investigation should aim at deriving conclusions on what actors should be approached by innovative companies, when a specific factor hampers or facilitates their development efforts.

Moreover, this study hypothesized market introduction as the ultimate goal in the innovation phase. However, this is a simplification. Products may fail even after market introduction. So, how could a successful market introduction be defined? E.g. Is it time-to-market, or volume of sales? What does this mean for innovative firms that are positioned within the innovation phase? In addition, what are the specific goals to be achieved by firms during the innovation phase according to the different theories that have been examined by this paper? Are these goals connected to specific factors and actors that have been distinguished here? The aforementioned questions should be of interests for further studies.

Finally, as a next step, future research should explore more advanced strategic issues concerning the innovation phase. For example:

- What strategies can be derived based on the existence of the barriers and facilitators identified here? (i.e. can we suggest specific strategies based on the presence of a specific set of barriers and/or facilitators? How do the barriers and facilitators relate to strategies?)
- How do barriers and facilitators to the first market introduction differ depending on the type of firms (e.g. start-ups, SMEs, or large corporations)? Are specific factors (barriers and facilitators) more relevant to specific types of firms?

Bibliography

Adams, R. (2013). Barcode History. Retrieved June 28, 2016, from http://www.adams1.com/history.html.

Ahlstrom, D. (2010). Innovation and Growth: How Business Contributes to Society. *Academy of Management Perspectives, 24*(3), 11-24.

Attaran, M. (2007). RFID: an enabler of supply chain operations. *Supply Chain Management: An International Journal*, *12*(4), 249-257. http://dx.doi.org/10.1108/13598540710759763

Cardullo, M. (2004). Genesis of the Versatile RFID Tag. Retrieved from RFID Journal. http://www.rfidjournal.com/articles/view?392

Cooper, R. G. (1988). Predevelopment activities determine new product success. *Industrial Marketing Management*, *17*(3), 237-247.

Cooper, R. G. (1990). Stage-gate systems: a new tool for managing new products. *Business horizons*, *33*(3), 44-54.

Cooper, R. G. (1998). Benchmarking new product performance: results of the best practices study. *European Management Journal*, *16*(1), 1-17.

Cooper, R. G. (1999). The invisible success factors in product innovation. *Journal of product innovation management*, *16*(2), 115-133.

Cooper, R. G., & Kleinschmidt, E. J. (1995). Benchmarking the Firm's Critical Success Factors in New Product Development. *Journal of Product Innovation Management, 12*(5), 374-391.

Damanpour, F. (1991). Organizational innovation: A meta-analysis of effects of determinants and moderators. *Academy of management journal*, *34*(3), 555-590.

Denyer, D., & Tranfield, D. (2009). Producing a systematic review.

Dobkin, D. M. (2013). *The RF in RFID: UHF RFID in Practice*. Elsevier/Newnes. 2nd. Ed.

Doering, R. (2006). The evolution of RFID technologies. In Harrington-Hughes, K. (2007). *Research Opportunities in Radio Frequency Identification Transportation Applications: October 17-18, 2006, Washington*. Transportation Research Board of the National Academies.

Domdouzis, K., Kumar, B., & Anumba, C. (2007). Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics, 21*(4), 350-355. doi: 10.1016/j.aei.2006.09.001

Dwyer, L., & Mellor, R. (1991). Organizational environment, new product process activities, and project outcomes. *Journal of Product Innovation Management*, *8*(1), 39-48.

Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2012). *Management research*. Sage.

Ernst, H. (2002). Success Factors of New Product Development: A Review of the Empirical Literature. *International Journal of Management Reviews Int J Management Reviews, 4*(1), 1-40.

Gao, J. Z., Prakash, L., & Jagatesan, R. (2007, July). Understanding 2d-barcode technology and applications in m-commerce-design and implementation of a 2d barcode processing solution. In *Computer Software and Applications Conference, 2007. COMPSAC 2007. 31st Annual International* (Vol. 2, pp. 49-56). IEEE.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, *31*(8), 1257-1274.

Gopalakrishnan, S., & Damanpour, F. (1997). A review of innovation research in economics, sociology and technology management. *Omega*, *25*(1), 15-28.

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological forecasting and social change*, *74*(4), 413-432.

Hensher, D. A. (1991). Electronic toll collection. *Transportation Research Part A: General*, *25*(1), 9-16.

Hunt, V. D., Puglia, A., & Puglia, M. (2007). *RFID: A guide to radio frequency identification*. Hoboken, NJ: Wiley-Interscience.

Jamali, B. (2011). The Evolution of RFID. *Handbook of Smart Antennas for RFID Systems*, pp. 1-12.

Jetter, A. (2003). Educating the guess: Strategies, concepts and tools for the fuzzy front end of product development. Technology Management for Reshaping the World, D. F. Kocaoglu and T. R. Anderson, Eds. Portland: PICMET, 2003, 261-273.

Kato, H., Tan, K. T., & Chai, D. (2010). *Barcodes for mobile devices*. Cambridge University Press.

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management, 10*(2), 175-198.

Khurana, A. & Rosenthal, S.R. (1997). Integrating the Fuzzy Front End of New Product Development. *Sloan Management Review* 38(2):103–120.

Koen, P., Ajamian, G., Burkart, R., & Clamen, A. (2001). Providing clarity and a common language to the" fuzzy front end". *Research Technology Management*, *44*(2), 46.

Landt, J. (2001). Shrouds of Time: The History of RFID. AIM Publications, Pittsburgh, PA.

Landt, J. (2005). The History of RFID, *IEEE Potentials*, vol. 24, no. 4, pp. 8-11.

Larsen, O. I. (1987). The toll ring in Bergen, Norway. *Transportation Research Record*, (1107).

Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strat. Mgmt. J. Strategic Management Journal, 13*(S1), 111-125.

Lumpkins, W. (2015). RFID: An Evolution of Change, from World War II to the Consumer Marketplace. *IEEE Potentials, 34*(5), 6-12. doi:10.1109/mpot.2015.2410374

Markham, S. K., Ward, S. J., Aiman-Smith, L., & Kingon, A. I. (2010). The Valley of Death as Context for Role Theory in Product Innovation. *Journal of Product Innovation Management, 27*(3), 402-417.

Marshall, C., & Rossman, G. B. (2014). *Designing qualitative research*. Sage publications.

Miles, S. (2008). Introduction to RFID history and markets. In Miles, S. B., Sarma, S. E., & Williams, J. R. (2008) *RFID technology and applications*. Cambridge, UK: Cambridge University Press.

Modgil, S., Patyal, V. S., & Agrawal, T. (2012). Technology Evolution in Supply Chain Management: BARCODE to RFID. *CPMR-IJT International Journal of Technology*, *2*(1), 27-32.

Murphy, S., & Kumar, V. (1997). The front end of new product development: A Canadian survey. *R&D Management, 27*(1), 5-15.

Nail, J. M., Anderson, G., Ceasar, G., & Hansen, C. J. (2003, September). The evolution of the pem stationary fuel cell in the us innovation system. In *International Conference on Innovation in Energy Technologies, Washington DC*.

Nieto, M. (2002). From R&D management to knowledge management: an overview of studies on innovation management. Technological Forecasting and Social Change 70, 135–161

OECD. (n.d.). Innovation in science, technology and industry. Retrieved January 10, 2016, from http://www.oecd.org/innovation/inno/inno-stats.htm

Ortt, J. R. (2010). Understanding the Pre-Diffusion Phases. In J. Tidd (Ed.), Gaining Momentum Managing the Diffusion of Innovations (pp. 47-80). London: Imperial College Press.

Ortt, J. R., & Schoormans, J. P. (2004). The pattern of development and diffusion of breakthrough communication technologies. *European Journal of Innovation Management, 7*(4), 292-302.

Ortt, J. R., & Smits, R. (2006). Innovation management: different approaches to cope with the same trends. *International journal of technology management*,*34*(3-4), 296-318.

Ortt, J. R., & van der Duin, P. A. (2008). The evolution of innovation management towards contextual innovation. *European Journal of Innovation Management*, *11*(4), 522-538.

Ortt, J. R., Langley, D. J., & Pals, N. (2013). Ten niche strategies to commercialize new high-tech products. *2013 International Conference on Engineering, Technology and Innovation (ICE) & IEEE International Technology Management Conference*.

Ortt, J. R., Zegveld, M., & Shah, C. M. (2007). Strategies to Commercialize Breakthrough Technologies. *SSRN Electronic Journal SSRN Journal*. *IAMOT 2007: 16th international conference on management of technology, May 13-17, 2007, Miami Beach, Florida, USA: Productivity enhancement for social advance: The role of management of technology: Program and book of abstracts*. (2007). Miami Beach: IAMOT.

Ortt, J.R. (2010). Understanding the Pre-Diffusion Phases. In J Tidd (Ed.), Gaining Momentum Managing the Diffusion of Innovations (pp. 47-80). London: Imperial College Press.

Paré, G., Trudel, M. C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*(2), 183-199.

Prahalad, C. K., & Hamel, G. (2006). *The core competence of the corporation* (pp. 275-292). Springer Berlin Heidelberg.

Reid, S. E., & Brentani, U. D. (2004). The Fuzzy Front End of New Product Development for Discontinuous Innovations: A Theoretical Model. *Journal of Product Innovation Management, 21*(3), 170-184.

Reyes, P. M., & Frazier, G. V. (2007). Radio frequency identification: past, present and future business applications. *International Journal of Integrated Supply Management*, *3*(2), 125-134.

Reynolds, T. (n.d.). A short history of barcode scanners. National Barcode. Retrieved June 28, 2016, from https://www.barcodesinc.com/articles/history-of-barcode-scanners.htm.

Roberti, M. (2007). A Small Piece of RFID History. Retrieved from RFID Journal. http://www.rfidjournal.com/blogs/rfid-journal/entry?3315

Roberts, C. M. (2006). Radio frequency identification (RFID). *Computers & Security*, *25*(1), 18-26.

Rogers, E. M. (2003). *Diffusion of innovations*. New York: Free Press.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management, 20*(5), 537-554.

Seideman, T. (1993). Barcodes sweep the world. *American Heritage of Invention and Technology*, *8*(4), 56-63.

Solow, R. M. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*, *39*(3), 312–320. http://doi.org/10.2307/1926047

Tidd, J. (2010). *Gaining momentum: Managing the diffusion of innovations*. London: Imperial College Press.

Trott, P. (2011). *Innovation management and new product development*. Harlow: Financial Times Prentice Hall.

Violino, B. (2005). The History of RFID Technology. Retrieved from RFID Journal. http://www.rfidjournal.com/articles/view?1338

Want, R. (2006). An introduction to RFID technology. *Pervasive Computing, IEEE*, *5*(1), 25-33.

Woodford, C. (2015). How do barcodes and barcode scanners work. Retrieved June 28, 2016, from http://www.explainthatstuff.com/barcodescanners.html.

Wu, N. C., Nystrom, M. A., Lin, T. R., & Yu, H. C. (2006). Challenges to global RFID adoption. *Technovation*, *26*(12), 1317-1323.

Yin, R. K. (2003). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.

Zhang, Q., & Doll, W. J. (2001). The fuzzy front end and success of new product development: A causal model. *European Journal of Innovation Management, 4*(2), 95-112.

Appendix A Case Database: Case A - RFID

Interpretation/Notes	Date	Evidence (Source)
Precursor – <u>Out of Scope</u>	1864	"The history of radio frequency engineering can be traced to 1864 when **James Clerk Maxwell predicted the existence of electromagnetic waves, of which microwaves are a part**, through Maxwell's equations." (Miles, 2008, p.4)
Precursor – <u>Out of Scope</u>	1888	"By 1888, **Heinrich Hertz had demonstrated the existence of electromagnetic waves by building an apparatus that produced and detected microwaves in the UHF region,** the radio frequency selected by the Auto-ID Center at MIT for its passive RFID initiative a century and a half later." (Miles, 2008, p.4)
Precursor – <u>Out of Scope</u>	1906	"In 1906, **Ernst F.W. Alexanderson showed how the first radio wave could be generated continuously and how radio signals could be transmitted**." (Domdouzis et al., 2007, p. 350) "In 1906, **Ernst F. W. Alexanderson demonstrated the first continuous wave (CW) radio generation and transmission of radio signals**. This achievement signals the beginning of modern radio communication, where all aspects of radio waves are controlled." (Landt, 2001, p. 3)
Precursor – <u>Out of Scope</u>	1922	"In the early 20th century, **approximately 1922, was considered the birth of radar**. The work in radar during World War II was as significant a technical development as the Manhattan Project at Los Alamos Scientific Laboratory, and was critical to the success of the Allies. […] Since **RFID is the combination of radio broadcast technology and radar**, it is not unexpected that the convergence of these two radio disciplines and the thoughts of RFID occurred on the heels of the development of radar." (Landt, 2001, p. 3-4)
Hallmark 1: Invention (<u>Accepted</u>) *Early Application*	1930s-1940s	"RFID is not a new technology. **It was first used in the Second World War to identify friendly aircraft**. […] RFID technology originated in the 1940s, when the **US Government used transponders to distinguish friendly aircraft from enemy aircraft**." (Attaran, 2007, p. 249-250) "**The problem of identifying as well as detecting potentially hostile aircraft challenged all combatants during World War II**. […] This curious behavior was eventually correlated with the interception of radio signals from the ground. […] **The consequent modulation of the blips on the radar screen allowed the German radar operators to identify these blips as friendly targets. This is the first known example (at least to the author) of the use of a passive backscatter radio link for identification**. […] More capable means of establishing the identity of radar targets were the subject of active investigation during the 1930's. **The United States and Britain tested simple IFF systems using an active beacon on the airplane (the XAE and Mark I, respectively) in 1937/1938. The Mark III system, widely used by**

		Britain, the US, and the Soviet Union during the war, employed a mechanically tunable receiver and transmitter with six possible identifying codes (that is, the ID space had grown to 2.5 bits). By the mid-1950's, the radar transponder still in general use in aviation today had arisen." (Dobkin, 2013, p. 7) "During World War II, the British wanted to distinguish between their own returning aircrafts and those of the enemy. For this reason, **they placed transponders on their aircrafts which would be able to respond appropriately to interrogating signals from base stations. This was called the Identity Friend or Foe (IFF) system which is widely considered the first use of Radio- Frequency Identification (RFID)** [5]." (Domdouzis et al., 2007, p. 351) "**The first RFID applications were developed in conjunction with radar technology at the height of the Second World War, for Identification Friend or Foe (IFF) systems, where the RF transponder (tag) and interrogator (reader) were designed to detect friendly airplanes**. [4]" (Miles, 2008, p.5) "**The Germans discovered that if pilots rolled their planes as they returned to base, it would change the radio signal reflected back. This crude method alerted the radar crew on the ground that these were German planes and not Allied aircraft (this is, essentially, the first passive RFID system)**." (Violino, 2005, p.1) "**An older technology that was first used during World War II for various communication protocols became what we now call radio frequency identification (RFID), which has become deployed almost worldwide now to track valuables and personal assets as well as for safety reasons.**" (Lumpkins, 2015, p. 6) "**Many authors date the origin of RFID to the 1940s during World War II. The Germans discovered that if their pilots rolled their planes as they were approaching their base, they could establish a secret handshake. The roiling of the planes modulated the reflected radar signal. The British, on the other hand, developed the first active identify friend or foe (IFF) system [2]. They placed a transmitter on each British plane that upon detecting a radar signal would broadcast back a signal that would identify the aircraft as friendly. An RFID system basically works on the same principles.**" (Jamali, 2010, p.6)
Scientific Knowledge	1948	"In 1948, a paper entitled **"Communication by Means of Reflected Power" written by Harry Stockman [18], was published**." (Domdouzis et al., 2007, p. 351)

		"RFID uses electromagnetic energy and its roots can be traced to research on the use of radar. One of the first major papers on RFID was by Harry Stockman (1948): **'Communication by means of reflected power', published in October 1948. He stated that the technology is imperfect and much research and development is needed before RFID technology can be put into practical use in various fields**." (Reyes and Frazier, 2007, p. 127) "**An early, if not the first, work exploring RFID is the landmark paper by Harry Stockman, "Communication by Means of Reflected Power", Proceedings of the IRE, pp1196-1204, October 1948. Stockman stated then that "Evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored**." **Thirty years would pass before Harry's vision would begin to reach fruition. Other developments were needed: the transistor, the integrated circuit, the microprocessor, development of communication networks, changes in ways of doing business. No small task. Like many things, timing is everything, and the success of RFID would have to wait a while**." (Landt, 2001, p. 4) "A more ambitious investigation of the use of backscattered radiation to communicate substantial information was reported by **Harry Stockman in 1948. […] This is the first example of a backscatter radio link conveying substantial amounts of information back to the transmitter**." (Dobkin, 2013, p. 10) "A major milestone toward modern RFID was the work by Harry Stockman in his **1948 paper, entitled "Communication by Means of Reflected Power." Stockman stated in his paper that ". . . considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved and before the field of useful applications is explored [3]." The discovery of semiconductor transistors in the 1950s enabled Stockman's vision of reflected power-coded communication to become a reality**." (Jamali, 2010, p. 6)
Scientific Knowledge and Firm-Specific Techniques	1950s	"The **main era of exploration of RFID technology began** in the 1950s by work done by F. L. Vernan [4] and D. B. Harris [5]." (Jamali, 2010, p. 6) "Other **important early papers on RFID** include 'Application of the microwave homodyne' (Vernon, 1952), 'Radio transmission systems with modulatable passive responder' (Harris, 1960) and 'Electronic identification system' (Klensch, 1975)." (Reyes and Frazier, 2007, p. 127)

		"In the early 1950's, **passive backscatter links of this type were investigated** with, among others, the object of creating an inexpensive wireless telephone system (the cellular phone being at that time very far in the future!), as exemplified in a 1960 patent due to Harris (US 2,927,321)." (Dobkin, 2013, p. 12) "The 1950s were **an era of exploration of RFID techniques following technical developments in radio and radar in the 1930s and 1940s**. […] **Developments of the 1950s include such works** as F. L. Vernon's, "Application of the microwave homodyne", and D.B. Harris', "Radio transmission systems with modulatable passive responder". The wheels of RFID development were turning." (Landt, 2001, p. 4) "**Extraction of DC from RF had already been envisioned in (for example) Crump's work in the 50's**, and by the early 70's Cardullo and Parks showed how this approach could be applied to power a more modern bit of circuitry" (Dobkin, 2013, p. 12)
Early Application and Commercialization	1960s	"Advances in radar and RF communications systems continued through the 1950s and 1960s. Scientists and academics in the United States, Europe and Japan did research and presented papers explaining how RF energy could be used to identify objects remotely. **Companies began commercializing anti-theft systems that used radio waves to determine whether an item had been paid for or not.** Electronic article surveillance tags, which are still used in packaging today, have a 1-bit tag. The bit is either on or off. If someone pays for the item, the bit is turned off, and a person can leave the store. But if the person doesn't pay and tries to walk out of the store, readers at the door detect the tag and sound an alarm." (Violino, 2005, p.1) "In the late 1960s, two companies called Sensormatic and Checkpoint were founded. These companies together with another company called Knogo, **developed the Electronic Article Surveillance (EAS) equipment to face the theft of merchandise** [12]." (Domdouzis et al., 2007, p. 351) "Commercial applications began to flourish in the past few decades. Companies such as Checkpoint, Sensormatic and Togo **developed Electronic Article Surveillance (EAS) systems to prevent retail theft**, **primarily of higher priced items**. **This commercial use of RFID** was quite effective in preventing theft." (Reyes and Frazier, 2007, p. 127) "In early 1960 many **companies began commercializing Electronic Article Surveillance (EAS) or anti-theft systems that are based on a very simple RFID concept.** These RFID tags that are still in use today have 1 bit of digital information." (Jamali, 2010, p. 6) "**Commercial activities were beginning in the 1960s**. Sensormatic and Checkpoint were founded in the late 1960s. These companies, with

		others such as Knogo, developed electronic article surveillance (EAS) equipment to counter theft. These types of systems are often use '1-bit' tags – only the presence or absence of a tag could be detected, but the tags could be made inexpensively and provided effective anti-theft measures. These types of systems used either microwave or inductive technology. **EAS is arguably the first and most widespread commercial use of RFID.**" (Landt, 2001, p. 4) "Such **transponders were developed in the 1960's for the purpose of preventing theft of retail goods**, and are still in wide use." (Dobkin, 2013, p. 11) "**A precursor to passive RFID was the electronic article surveillance (EAS) systems deployed in retail stores in the 1970s** that used dedicated short-range communication (DSRC) RF technology for anti-theft detection." (Miles, 2008, p. 5)
Scientific Knowledge and Firm-Specific Techniques	1960s	"In 1964, R.F. Harrington [10] **examined the electromagnetic theory related to RFID in his paper** ''Theory of Loaded Scatterers''." (Domdouzis et al., 2007, p. 351) "The 1960s were the prelude to the RFID explosion of the 1970s. R. F. Harrington **studied the electromagnetic theory related to RFID in his papers** "Field measurements using active scatterers" and "Theory of loaded scatterers" in 1963-1964. **Inventors were busy with RFID related inventions** such as Robert Richardson's "Remotely activated radio frequency powered devices" in 1963, Otto Rittenback's "Communication by radar beams" in 1969, J. H. Vogelman's "Passive data transmission techniques utilizing radar beams" in 1968 and J. P. Vinding's "Interrogator-responder identification system" in 1967." (Landt, 2001, p. 4)
Hallmark 2: First Market Introduction (<u>Accepted</u>)	1964-1970	"Ronald Assaf's frustration with shoplifters came to a head the day he watched a man slip two bottles of wine under his shirt and run out of an Akron, Ohio, supermarket. Assaf, the store manager, sprinted out the door in pursuit of the thief. Unable to catch the man and unsure what he would have done if he had caught him, Assaf returned to the store. He commented that anyone who could figure out a way to deter such thieves would make a fortune. One of those who heard his remark was his cousin, Jack Welch. Welch was already working on electronic tagging of products, and he took up Assaf's challenge. Several weeks later, Welch returned to the store with a 2 ft (61 cm) square of cardboard with a large foil tag taped to it, along with some bulky boxes filled with electronic components he had assembled in his garage. He showed Assaf how an alarm would sound if someone tried to carry the tag out the door between the boxes. A couple of years later, Assaf founded Sensormatic Electronics Corporation, which still holds a 65% share of the worldwide electronic security market.

		The very first EAS system that was based on Radio Frequency (RF) technology was designed by Arthur Minasy, the founder of "Knogo"." (Easlabel, 2015, n.p.) "The first EAS system was designed by Arthur Minasy in the mid-1960's, based on Radio Frequency (RF) technology. As a boy, Artur Minasy used to shoplift. He stole marbles, erasers, pencils and tennis balls. This is a fun fact considering that the very same boy grew up to create a multi-billion-dollar industry, that helps prevent theft. Others had tried before him by loading tags, for example, with small amounts of radioactive material, which would be detected by a Geiger counter at the store's exit. Reasonably the government prohibited that. Minasy, who was an electrical engineer by profession, had a simple approach: he crafted a plastic tag embedded with a metal coil, which was a really small antenna that responded to radio frequencies. He also built a portal to surround a doorway which set off an alarm. Competition gets stronger Very shortly afterwards Ronald G. Assaf, the founder of Sensormatic Electronics Corporation, developed a microwave-based (UHF) EAS system which was primarily targeted at department and apparel stores. Around the same time, George J Lichtblau developed Swept RF technology and licensed his patents to Checkpoint which created a commercial product by the start of the 1970's. For the first 20 years of their history, security tags used swept radio frequency (swept-RF) technology, which relied on a semiconductor diode to retransmit a high-frequency radio signal from the detection gates. Although the tags worked reasonably well, they had certain limitations." (Agon, 2015, n.p.)
Scientific Knowledge and Firm-Specific Techniques	Late 1960s	"Though much identification activity in this period was taking place at relatively low frequencies, the UHF band was not ignored. **Work had begun at Sandia National Laboratories in Albuquerque in the late 1960's to produce passive identifying systems operating at radar-like frequencies**" (Dobkin, 2013, p. 12)
Opportunity *Product Vision*	1969	"In 1969, I was the corporate planning officer to chairman of the Communications Satellite Corporation (Comsat). In the spring of 1969, I was seated next to an IBM engineer on a flight to Washington, from St. Paul. The engineer was implementing the CARTRAK optical system for the railroad industry. This system consisted of a reflective color bar code placed on the side of each railroad car. As the railroad car passes an optical base station, the station would transmit a beam of light. The optical bar code would reflect back a signal associated with the individual car so it could be identified. There were a number of problems with the CARTRAK system. […] I was well aware of the friend or foe systems and EAS security devices and believed that these concepts could be expanded upon to offer an alternative to the optical reflector systems being deployed. After the IBM engineer finished talking, **I started to sketch in my notebook the idea for the RFID tag with a changeable memory**. **The original sketch showed a**

		device with a transmitter, receiver, internal memory, and a power source." (Cardullo, 2003, p. 1-2) "One of the first major adopters of RFID technology in this area was the rail industry in the United States. This far-flung industry was faced with the problem of keeping track of tens of thousands of rail cars across tens of thousands of kilometers of track, made more challenging by the fact that companies often swapped cars in order to avoid paying to move empty cars. In the 1970's, the railways tried to make use of a circular bar code identifier, but optical identification in the rainy, muddy, snowy outdoors didn't work very well. (**In fact, it was the railcar identification problem that Mr. Cardullo relates as triggering his earliest work in RFID.**)" (Dobkin, 2013, p. 15)
Business Plan Preparation *Product Concept and Definition*	1969	"[…] During this period […] **I met Daniel Webster, a "cashed out" computer executive. Mr. Webster was excited about the concept I had for a new company, Communications Services Corporation (ComServ). He asked me to put together a management team and prepare a business plan.**" On returning to the Washington, I met with several individuals I knew whom had various competencies, marketing, finance and electronic development. One of those individuals was Bill Parks, a brilliant electronics engineer. **Putting my management team together we started work on a business plan**. **The principal product and service chosen was the EKG terminal and processing service. We also chose a series of electronic products that we thought would be follow-on products**, since we did not want to be what the venture capital industry refers to as a "one-trick pony". **One of the products was the initial RFID tag I had sketched earlier that year. After much discussion, we decided to present to Mr. Webster an RFID tag based on a passive transponder with a changeable memory instead of an active battery operated device. The illustration is a page from the original business plan that showed the basic concept that we entitled the "Encoder"**." (Cardullo, 2003, p. 1-2)
Social Networks *Financial Resources* *Scientific Knowledge and Firm-Specific Techniques*	1969	"We estimated that the new company would require a capitalization of $500,000 to start followed by additional capital of several million once the initial product and service was developed. When we presented the business plan to Mr. Webster he was extremely pleased. **However, when we outlined the plan to develop a passive transponder with a changeable memory for use as a toll system he literally was ecstatic. Within a week of our meeting with Mr. Webster checks averaging $50,000 from various investors' he had met with started to arrive at my mailbox. Once the funds were available my management team and I left our positions and started ComServ.** ComServ was the first company I had started. […] **I chose, Bill Parks to be our vice president of engineering. He hired a small group of development engineers and technicians, which immediately started**

		developing our two basic products and services, the EKG terminal and the RFID tag." (Cardullo, 2003, p. 1-2)
Scientific Knowledge and Firm-Specific Techniques	1970	"During this period the technical staff started on the process of building the first RFID Tag. **In 1970, the only non-volatile memory was ferrite cores that were used in mainframe computers. We needed a small number, sufficient for 16 bits. To achieve this, we purchased small ferrite donuts which served as memory cells that we then hand wound to obtain the non-volatile memory. We built a breadboard unit that we could demonstrate the system.**" (Cardullo, 2003, p. 1-2)
Hallmark 1: Invention (?) (<u>Rejected</u>) *Entrepreneur Licensing out his Technology to a Company – <u>Out of Scope</u>*	1970-1973	"On May 21, 1970, **they filed on our behalf the patent application for the RFID tag. The U.S. Patent Office issued the patent on January 23, 1973** […]" (Cardullo, 2003, p. 1-2) "**Mario W. Cardullo claims to have received the first U.S. patent for an active RFID tag with rewritable memory on January 23, 1973**. That same year, Charles Walton, a California entrepreneur, received a patent for a passive transponder used to unlock a door without a key. A card with an embedded transponder communicated a signal to a reader near the door. When the reader detected a valid identity number stored within the RFID tag, the reader unlocked the door. **Walton licensed the technology to Schlage, a lock maker, and other companies**." (Violino, 2005, p. 1) "**The first patent on RFID technology was granted to Mario Cardullo in 1973 [6]. Cardullo's invention was the first true ancestor of modern RFID**: "A passive radio transponder with memory." Cardullo's RFID tag was designed to be used as a toll device, and there were a number of potential users, including the New York Port Authority." (Jamali, 2010, p. 6)
Competition at the project level *Parallel R&D Efforts*	1970s	"While ComServ was building the RFID Tag with a changeable memory, **others were also engaged in developing similar concepts** including Los Alamos Scientific Laboratory, Northwestern University, and the Microwave Institute Foundation in Sweden. However, ComServ was the first to receive a very generic patent." (Cardullo, 2003, p. 2-3) "In the 1970s **developers, inventors, companies, academic institutions, and government laboratories were actively working on RFID**, and notable advances were being realized at research laboratories and academic institutions such as Los Alamos Scientific Laboratory, Northwestern University, and the Microwave Institute Foundation in Sweden among others." (Landt, 2001, p. 4-5)
Technological/Market Niche selected by Government (?) - <u>Out of Scope</u>	Early 70s	"**At the request of the Agricultural Department, Los Alamos also developed a passive RFID tag to track cows.** The problem was that cows were being given hormones and medicines when they were ill. But it was hard to make sure each cow got the right dosage and wasn't given two doses accidentally. Los Alamos came up with a passive RFID system that used UHF radio waves. The device drew energy from the

		reader and simply reflected back a modulated signal to the reader using a technique known as backscatter." (Violino, 2005, p. 1) "A project leader at Los Alamos National Laboratory, which **developed one of the first RFID systems for the U.S. Department of Agriculture** back in the early 1970s" (Roberti, 2007, p. 1) "Through the 1970s, **the federal government primarily used the systems for tracking livestock and nuclear material**." (Attaran, 2007, p. 250)
Technological/Market Niche selected by Government (?) - <u>Out of Scope</u>	1970s	"**The U.S. government was also working on RFID systems. In the 1970s, Los Alamos National Laboratory was asked by the Energy Department to develop a system for tracking nuclear materials.** A group of scientists came up with the concept of putting a transponder in a truck and readers at the gates of secure facilities. The gate antenna would wake up the transponder in the truck, which would respond with an ID and potentially other data, such as the driver's ID. This system was commercialized in the mid-1980s when the Los Alamos scientists who worked on the project left to form a company to develop automated toll payment systems. These systems have become widely used on roads, bridges and tunnels around the world." (Violino, 2005, p. 1) "Through the 1970s, **the federal government primarily used the systems for tracking livestock and nuclear material**." (Attaran, 2007, p. 250)
Barriers to implementation of vision: *Cost* *Regulatory* *Social* *Facilitators:* *Technological Advancement in Enabling Technologies*	Early 1970s-1980s	"**By the early 1970's, the rapidly decreasing cost of electronic components had led to the demonstration of more sophisticated identifying systems using inductive coupling, UHF backscatter radios, and microwave radios**, as described in section 2 above. One of the obvious applications of such non-contact identifying technologies was traffic management, because automobiles and trucks are expensive, mobile, and uniquely identified with an owner or owners. The application of RFID techniques to traffic control at this time was nicely summarized in an article by William Arnold, published in Electronics in September of 1973. After reviewing some of the major pilot projects, Mr. Arnold provides a remarkably prescient list of the applications envisioned for RFID: toll collection, toll parking, dynamic traffic control, vehicle identification, trucking location, and surveillance. **The implementation of these visions was largely constrained by barriers of cost, regulation, and institutional risk, though early observers were also already concerned about driver privacy. The main solution to the obstacle of cost was time: during the 1970's and 1980's semiconductor manufacturing improved dramatically and the cost of virtually all electronic goods fell commensurately."** (Dobkin, 2013, p. 15)
Supply/Infrastructure Networks	1970	"**The concept was also presented to the Southern (now Norfolk Southern) Railroad that several months prior had chosen the**

		CARTRAK optical system. I also made a presentation to the Director of the Public Works Committee of the U.S. House of Representatives. At that meeting, I presented the concept as a means of foiling car thieves and as a means of charging people for the use of the Interstate Highway system based on mileage." (Cardullo, 2003, p. 2-3)
Supply/Infrastructure Networks *Legislation (Laws); Perceived User Preferences; Cultural Meaning of the Technology*	1971	"In 1971, we went to New York to meet with New York Port Authority representatives. **We showed them the concept and how it could be used in an automated toll collection system**. **At that meeting the representative of the Port Authority told us "no one will ever mount those transponders on their car windows". He also thought that the system would lead to invasion of privacy and could be "unconstitutional".**" (Cardullo, 2003, p. 1-2)
Supply/Infrastructure Networks *Vested Interests (?) – <u>Out of Scope</u>*	1971-1973	"**Within two years, the New York Port Authority had contracted to test a system similar to the issued patent (January 1973) but supplied by GE, Glenayre, Philips, and Westinghouse Air Brake**. **We can now question the propriety of what happened between our meeting with the Port Authority in 1971 and their tests in 1973.** We met similarly with the San Francisco Port Authority who participated in the test with the New York Port Authority. (Cardullo, 2003, p. 2-3)
Regulation (Rules and Standards) – <u>Out of Scope</u>	1973	"The Port Authority of New York and New Jersey were also testing systems built by General Electric, Westinghouse, Philips and Glenayre. **Results were favorable, but the first commercially successful transportation application of RFID, electronic toll collection, was not yet ready for prime time.**" (Landt, 2001, p. 4-5) "Transportation efforts included work at Los Alamos and by the International Bridge Turnpike and Tunnel Association (IBTTA) and the United States Federal Highway Administration. The latter two sponsored **a conference in 1973 which concluded there was no national interest in developing a standard for electronic vehicle identification**. This is an important decision since it would permit a variety of systems to develop, which was good, because RFID technology was in its infancy." (Landt, 2001, p. 4-5) "During the 70s, research laboratories and universities, such as the Los Alamos Scientific Laboratory and Northwestern University were involved in RFID research. The Los Alamos Scientific Laboratory, the International Bridge Turnpike and Tunnel Association (IBTTA) and the United States Federal Highway Administration organised **in 1973 a conference on RFID which concluded that there was no national interest in the development of a standard for vehicle identification.** This decision lead to the development of a range of systems." (Domdouzis et al., 2007, p. 351)
Social Networks (?) – <u>Out of Scope</u>	1973	"**By the end of 1973, I had left the ComServ after a disagreement with my original investors. Within a year the company had closed.** The development of the RFID concepts continued. Raytheon, RCA and Fairchild had systems by 1973-1975 time period. The developments

		continued into the 1980's. On January 23, 1990, the original patent expired without further patents by ComServ." (Cardullo, 2003, p. 2-3) "The 1990's was a period of significant growth of the RFID tag concept by the wide scale deployment of electronic toll collection systems. Today, the RFID Tag in its various configurations is becoming ubiquitous. **While I never benefited financially from my RFID invention**, I do look with pride on its use today. **Many of the applications I envisioned for it in the early 1970s are now being widely adopted.**" (Cardullo, 2003, p. 2-3)
Hallmark 2: First Market Introduction (?) (<u>Rejected</u>) – <u>Out of Scope</u>	1972-1973	"A transponder with a larger potential ID space, but still inexpensive and compact and with no need for a battery, may be achieved by using a resonant circuit, composed of a capacitor and inductor which together determine a unique frequency at which a large current flows through the transponder. The resonant frequency can be readily varied by adjusting the values of the components. Charles Walton, among others, patented several types of inductive identifying transponders in the early 1970's. […] **Tags of this type were used in one of the first major commercial implementations of RFID technology by the Schlage Lock Company around 1972-73. Several million electronic keys, using multiple resonators in the 3-32 MHz region, were produced**" (Dobkin, 2013, p. 12)
Sequential Development Efforts – <u>Out of Scope</u>	1973-1978	"Large companies, such as **Raytheon and RCA developed electronic identification systems in 1973 and in 1975**, respectively." (Domdouzis et al., 2007, p. 351) "**Large companies were also developing RFID technology, such as Raytheon's "Raytag" in 1973. RCA and Fairchild were active in their pursuits with Richard Klensch of RCA developing an "Electronic identification system" in 1975 and F. Sterzer of RCA developing an "Electronic license plate for motor vehicles" in 1977. Thomas Meyers and Ashley Leigh of Fairchild also developed a "Passive encoding microwave transponder" in 1978."** (Landt, 2001, p. 4-5)
Scientific Knowledge and Firm-specific Techniques - <u>Out of Scope</u>	1975	"**Major events in commercial RFID development can further be traced to the declassification in 1975 by Los Alamos Scientific Labs with their published research**: 'Short-range radio-telemetry for electronic identification using modulated backscatter' (Koelle, 1975)." (Reyes and Frazier, 2007, p. 127) "An **early and important development was the Los Alamos work** that was presented by Alfred Koelle, Steven Depp and Robert Freyman "Short-range radio-telemetry for electronic identification using modulated backscatter" in 1975." (Landt, 2001, p. 4-5)
Scientific Knowledge and Firm-specific Techniques – <u>Out of Scope</u>	1978	"In 1978, **R.J. King [11] wrote a book about microwave homodyne techniques**. This book has been used as the basis for the development of the theory and practice which are used in backscatter RFID systems [12]." (Domdouzis et al., 2007, p. 351)

Hallmark 2: First Market Introduction (?) – <u>Out of Scope</u>	Mid 1980s	"The U.S. government was also working on RFID systems. In the 1970s, Los Alamos National Laboratory was asked by the Energy Department to develop a system for tracking nuclear materials. A group of scientists came up with the concept of putting a transponder in a truck and readers at the gates of secure facilities. The gate antenna would wake up the transponder in the truck, which would respond with an ID and potentially other data, such as the driver's ID**. This system was commercialized in the mid-1980s when the Los Alamos scientists who worked on the project left to form a company to develop automated toll payment systems.** These systems have become widely used on roads, bridges and tunnels around the world." (Violino, 2005, p. 1) "[…] About this time new companies began to surface, such as Identronix**, a spin-off from the Los Alamos Scientific Laboratory, and others of the Los Alamos team, myself being one of them, founded Amtech (later acquired by Intermec and recently sold to TransCore) in the 80s.** By now, the number of companies, individuals and institutions working on RFID began to multiply. A positive sign. The potential for RFID was becoming obvious." (Landt, 2001, p. 4-5)
Hallmark 1: First Market Introduction (?) (<u>Rejected</u>) – <u>Out of Scope</u>	1987	"The 1980s became **the decade for full implementation of RFID technology, though interests developed somewhat differently in various parts of the world.** The greatest interests in the United States were for transportation, personnel access, and to a lesser extent, for animals. In Europe, the greatest interests were for short-range systems for animals, industrial and business applications, though toll roads in Italy, France, Spain, Portugal, and Norway were equipped with RFID. In the Americas, the Association of American Railroads and the Container Handling Cooperative Program were active with RFID initiatives. **Tests of RFID for collecting tolls had been going on for many years, and the first commercial application began in Europe in 1987 in Norway** and was followed quickly in the United States by the Dallas North Turnpike in 1989. Also during this time, the Port Authority of New York and New Jersey began commercial operation of RFID for buses going through the Lincoln Tunnel. RFID was finding a home with electronic toll collection, and new players were arriving daily." (Landt, 2001, p. 5) "**In 1987, the first commercial application of RFID was developed in Norway** and was followed by the Dallas North Turnpike in the United States in 1989." (Domdouzis et al., 2007, p. 351)

Appendix B Case Database: Case B - Barcode

Interpretation/Notes	Date	Evidence (Source)
Prior vision to satisfy the same market need with another system	1890	"As the corner grocery store grew and started stocking more and more products to keep its customer's happy, the ability to understand just what was on the shelf and to re-order items sold became more and more critical to the financial success of the all grocery businesses. **Before the development of the barcode scanner, the only way to get an accurate inventory of stock on the shelves and in the back room was to do a manual count of each and every item in the store**. Time consuming and expensive to complete, instead of manual inventories, most store managers based their ordering decisions on crude estimates and arbitrary feelings. Most inventories were done infrequently, on average of once per month. Supermarket management personnel realized they were in a competitive marketplace, and that shopper's patronage relied on having the products they desired on-hand - all the time. Some owners considered using the punch-card technology that was developed in the late 19th century to complete the US Census. The vision was that the customer would punch the cards to mark their selections, the cards would be put in a reader at check-out, and a sales tally by product would be kept for the re-ordering process. But the consumer market was moving towards more convenience and time savings, and the proposal wasn't even prototyped." (Reynolds, n.d.) "Supermarkets are a perilous business. They must stock thousands of products in scores of brands and sizes to sell at painfully small markups. Keeping close track of them all, and maintaining inventories neither too large nor too small is critical. Yet for most of this century, **as stores got bigger and the profusion on the shelves multiplied, the only way to find out what was on hand was by shutting the place down and counting every can, bag, and parcel.** This expensive and cumbersome job was usually done no more than once a month. Store managers had to base most of their decisions on hunches or crude estimates Long before bar codes and scanners were actually invented, grocers knew they desperately needed something like them. Punch cards, first developed for the 1890 U.S Census, seemed to offer some early hope." (Seideman, 1993)
Development of different technology satisfying the same market need	1932	"In 1932 an ambitious project was conducted by a small group of students headed by Wallace Flint at the Harvard University Graduate School of Business Administration. **The project proposed that customers select desired merchandise from a catalog by removing corresponding punched cards from the**

		catalog. These punched cards were then handed to a checker who placed the cards into a reader. The system then pulled the merchandise automatically from the storeroom and delivered it to the checkout counter. A complete customer bill was produced and inventory records were updated." (Adams, 2010) "In 1932, a business student named Wallace Flint wrote a master's thesis in which he envisioned a supermarket where **customers would perforate cards to mark their selections; at the checkout counter they would insert them into a reader, which would activate machinery to bring the purchases to them on conveyer belts. Store management would have a record of what was being bought**. The problem was, of course, that the card reading equipment of the day was bulky, utterly unwieldy, and hopelessly expensive. Even if the country had not been in the middle of the Great Depression, Flint's scheme would have been unrealistic for all but the most distant future. Still, it foreshadowed what was to come." (Seideman, 1993)
Communication of a specific market need *Hallmark 1: Invention (Accepted)* *Patent Application*	1948-1949	"**We can trace the idea of the modern barcode to around 1948**, when a graduate student at the Drexel Institute in Philadelphia heard a conversation between one of the faculty and an executive of a food store chain. **The executive was trying to convince the faculty member to have the school develop a system to quickly and accurately capture product data at the check-out counter. The student, Bernie Silver related the conversation to Norman "Joe" Woodland, a teacher at the institute. The problem intrigued Woodland, and for the next 2 years he would experiment with a variety of data collection techniques to find the one that worked.** **Woodland "invented" the first barcode, basically by using Morse code - a series of dots and dashes used in telegraph and radio communications. Woodland wrote out the dots and dash representation of the product number and extended the lines of each vertically creating the first linear barcode. To read the barcode, Woodland adapted the DeForest movie sound system from 20 years earlier that used a sensitive tube to detect the projector light shining through the side of the film. In the movie industry, the light detected would be converted into sound. In Woodland and Silver's adaptation, the reflected light would be converted to numbers.** **In order to make the code readable from any direction, Woodland converted the lines into a circle - appearing like an archery target. Today, this type of code is known as the "bulls-eye" code. Convinced of the viability of their ideas, Silver and Woodland applied to patent the idea in late 1949**." (Reynolds, n.d.)

		“**Modern bar code began in 1948**. Bernard Silver, a graduate student at Drexel Institute of Technology in Philadelphia, overheard **the president of a local food chain asking one of the deans to undertake research to develop a system to automatically read product information during checkout. Silver told his friend Norman Joseph Woodland about the food chain president's request. Woodland was a twenty-seven-year-old graduate student and teacher at Drexel. The problem fascinated Woodland and he began to work on the problem**. **Woodland's first idea used patterns of ink that would glow under ultraviolet light. Woodland and Silver built a device which worked, but the system had problems with ink instability and it was expensive to print the patterns. Woodland was still convinced they had a workable idea. Woodland took some stock market earnings, quit his teaching job at Drexel, and moved to his grandfather's Florida apartment to have more time to work on the problem.** **On October 20, 1949, Woodland and Silver filed a patent application titled "Classifying Apparatus and Method." The inventors described their invention as relating "to the art of article classification...through the medium of identifying patterns".** **Most bar code histories state that the Woodland and Silver bar code was a "bull's eye" symbol, a symbol made up of a series of concentric circles. While Woodland and Silver did describe such a symbol, the basic symbology was described as a straight line pattern quite similar to present day linear bar codes like UPC and Code 39**.” (Adams, 2010) “**The first step toward today's bar codes came in 1948**, when Bernard Silver, a graduate student, overheard a conversation in the halls of Philadelphia's Drexel Institute of Technology. T**he president of a food chain was pleading with one of the deans to undertake research on capturing product information automatically at checkout. The dean turned down the request, but Bob Silver mentioned the conversation to his friend Norman Joseph Woodland, a twenty-seven-year-old graduate student and teacher at Drexel. The problem fascinated Woodland.** **His first idea was to use patterns of ink that would glow under ultraviolet light, and the two men built a device to test the concept. It worked, but they encountered problems ranging from ink instability to printing costs. Nonetheless, Woodland was convinced he had a workable idea. He took some stock market earnings, quit Drexel, and moved to his grandfather's Florida apartment to seek solutions. After several months of work, he came up with the linear bar code, using elements from two established technologies: movie soundtracks and Morse code.**

		Woodland, now retired, remembers that after starting with Morse code, "I just extended the dots and dashes downwards and made narrow lines and wide lines out of them." To read the data, he made use out of Lee de Forest's movie sound system from the1920's. De Forest had printed a pattern of varying degrees of transparency on the edge of the film, then shone a light through it as the picture ran. A sensitive tube on the other side translated the shifts in brightness into electric waveforms, which were in turn converted to sound by loudspeakers. Woodland planned to adapt this system by reflecting light off his wide and narrow lines and using a similar tube to interpret the results. **Woodland took his idea back to Drexel, where he began putting together a patent application. He decided to replace his wide and narrow lines with concentric circles, so that they could be scanned from any direction. This became known as the bull's-eye code. Meanwhile, Silver investigated what form the codes should ultimately take. The two filed a patent application on October 20, 1949.**" (Seideman, 1993)
Scientist/Entrepreneur joins company in order to develop his invention *Technology: Technology was imperfect and faced several limitations; Technological advances were necessary before it could be applied*	1951-1952	"**In 1951 Woodland got a job at IBM, where he hoped his scheme would flourish.** The following year he and Silver set out to build the first actual bar code reader – in the living room of Woodland's house in Binghamton, New York. The device was the size of a desk and had to be wrapped in black oilcloth to keep out ambient light. It relied on two key elements: a five-hundred-watt incandescent bulb as the light source and an RCA935 photo-multiplier tube, designed for movie sound systems, as the reader. Woodland hooked the 935 tube up to an oscilloscope. Then he moved a piece of paper marked with lines across a thin beam emanating from the light source. The reflected beam was aimed at the tube. At one point the heat from the powerful bulb set the paper smoldering. Nonetheless, Woodland got what he wanted. As the paper moved, the signal on the oscilloscope jumped. **He and Silver had created a device that could electronically read printed material.** **It was not immediately clear how to transform this crude electronic response into a useful form. The primitive computers of the day were cumbersome to operate, could only perform simple calculations, and in any case were the size of a typical frozen-food section. The idea of installing thousands of them in supermarkets from coast to coast would have been pure fantasy. Yet without a cheap and convenient way to record data from Woodland and Silver's codes, their idea would have been no more than a curiosity.** **Then there was that five-hundred-watt bulb. It created an enormous amount of light, only a tiny fraction of which was read by the 935 tube. The rest was released as expensive, uncomfortable waste heat. "That bulb was an awful thing to look**

		at," Woodland recalls. "It could cause eye damage." The inventors needed a source that could focus a large amount of light into a small space. Today that sounds like a prescription for a laser, but in 1952 lasers did not exist. In retrospect, bar codes were clearly a technology whose time had nowhere near come. **But Woodland and Silver, sensing the potential, pressed on. In October 1952 their patent was granted**." (Seideman, 1993)
Patent Grant	1952	**"Taking a job at IBM, Woodland built a prototype reader in his house using the technology of the day which included a high wattage incandescent bulb. As big as a large trunk, it demonstrated that the technology could work. The problem was converting the output into something meaningful for a store's manager or customers. Woodland approached his bosses at IBM to develop the technology, who offered to buy the patent that was granted in 1952, but Woodland and Silver held out to get a price that more closely reflected the potential of the technology**." (Reynolds, n.d.) "**The Woodland and Silver patent application was issued October 7, 1952 as US Patent 2,612,994**." (Adams, 2010) "**But Woodland and Silver, sensing the potential, pressed on. In October 1952 their patent was granted.**" (Seideman, 1993)
Licensing out the patent to a company (<u>Rejected by triangulation</u>)	1952	"In 1962 Silver died at age thirty-eight (in an automobile accident) before having seen the commercial use of bar code. Woodland was awarded the 1992 National Medal of Technology by President George Herbert Walker Bush. Neither Silver nor Woodland made much money on the idea that started a billion-dollar business. **That was because they sold the patent to RCA in 1952 for a small sum of money, long before any commercialization of the technology**." (Adams, 2010)
Consultant hired in order to evaluate the patent *Disagreement on the price of the patent between company and scientist within the company*	Late 1950s	"Woodland stayed with IBM and **in the late 1950's persuaded the company to hire a consultant to evaluate bar codes. The consultant agreed that they had great possibilities but said they would require a technology that lay at least five years off**. By now almost half the seventeen-year life of Woodland and Silver's patent had expired. **IBM offered a couple of times to buy the patent, but for much less than they thought it was worth**." (Seideman, 1993) "**Woodland approached his bosses at IBM to develop the technology, who offered to buy the patent that was granted in 1952, but Woodland and Silver held out to get a price that more closely reflected the potential of the technology**." (Reynolds, n.d.)
Development efforts by other inventors in	Late 1950s - 1960s	"**Meanwhile, various inventors proposed other methods of collecting product data during the late 1950's and through the 1960's. Of note is a railway car tracking system developed by**

order to satisfy the same market need *Actor: Scientist within a company* *Technology developed for an industrial application* *Tests last 10 years* *Technology becomes available to the market but fails because of its cost and usefulness*		**David Collins of the Sylvania Corporation. The system used a series of colored stripes made of reflective materials that represented a 10-digit number. A Sylvania computer interpreted and displayed the data to the operators. As the car entered the yard, colored lights would shine on the label, with a light sensor "decoding" the results. The system was first tested in 1961, and was available for purchase in the early 1970's, but the equipment was costly and cumbersome. Strapped for cash with the proliferation of the automobile, the industry underwent a shake-up in the recession of 74-76, and the system died when the interstate truck replaced the supremacy of the train as the major freight mover in the country. Reading the writing on the wall, Collins left Sylvania and founded Computer Identics.**" (Reynolds, n.d.) "Freight cars are nomads, wandering all across the country and often being lent from one line to another. **Keeping track of them is one of the most complex tasks the railroad industry faces, and in the early 1960's it attracted the attention of David J. Collins**. Collins got his master's degree from MIT in 1959 and immediately **went to work for the Sylvania Corporation, which was trying to find military applications for a computer it had built. During his undergraduate days Collins had worked for the Pennsylvania Railroad and he knew that the railroads needed a way to identify cars automatically and then to handle the information gathered. Sylvania's computer could do the latter; all Collins needed was a means to retrieve the former. Some sort of coded label seemed to be the easiest and cheapest approach.** **Strictly speaking, the labels Collins came up with were not bar codes. Instead of relying on black bars or rings, they used groups of orange and blue stripes made of a reflective material, which could be arranged to represent the digits 0 through 9. Each car was given a four-digit number to identify the railroad that owned it and a six-digit number to identify the car itself. When cars went into a yard, readers would flash a beam of colored light onto the codes and interpret the reflections. The Boston & Maine conducted the first test of the system on its gravel cars in 1961**." (Seideman, 1993)
Licensing out the patent to a company	1962	"**In the early 1960's they sold the patent to Philco, who eventually sold it to RCA."** (Reynolds, n.d.) "**In 1962 Philco met their price, and they sold. (The following year Silver died at age thirty-eight.) Philco later sold the patent to RCA**." (Seideman, 1993)
Company sells the patent to another company	1962-1966	"**In the early 1960's they sold the patent to Philco, who eventually sold it to RCA.**" (Reynolds, n.d.)

		"**In 1962 Philco met their price, and they sold. (The following year Silver died at age thirty-eight.) Philco later sold the patent to RCA**." (Seideman, 1993)
Industry conference motivates actors to develop the technology *Development included collaboration with an early adopter business*	1966	"Remember the Silver-Woodland patent purchased eventually by RCA? **By attending an industry conference in 1966, executives at that company became convinced that using barcode scanners at check-out was an emerging and lucrative market. They developed a bullseye symbol and a scanner that was installed and operating in a Cincinnati Kroger store beginning in 1972.** Although the system generated valuable Return-on-Investment data, printing problems with the bulls-eye barcodes and scanning problems limited its usefulness." (Reynolds, n.d.) "Already RCA was moving to assist the industry. **RCA executives had attended a 1966 grocery industry meeting where bar-code development had been urged, and they smelled new business. A special group went to work at an RCA laboratory in Princeton New Jersey, and the Kroger grocery chain volunteered itself as a guinea pig.** Then, in mid-1970, an industry consortium established an ad hoc committee to look into bar codes. The committee set guidelines for bar code development and created a symbol selection subcommittee to help standardize the approach." (Seideman, 1993)
(Macro) Technological Developments	Late 1960s – 1970s	"**Two technological developments of the 1960s finally made scanners simple and affordable enough. Cheap lasers were one. The other was integrated circuits. When Woodland and Silver first came up with their idea, they would have needed a wall full of switches and relays to handle the information a scanner picked up; now it's all done by a microchip**." (Seideman, 1993) "**With the technological progress of the late 60's to early 70's, transistors and laser components were getting less expensive, and computer processors continued to shrink in size.**" (Reynolds, n.d.)
Market Institution (representing industry) calls for technology *Hallmark 2: First market introduction (?) (<u>Rejected by triangulation</u>)*	1967	"**The National Association of Food Chains (NAFC) put out a call to equipment manufacturers for systems that would speed the checkout process. In 1967 RCA installed one of the first scanning systems at a Kroger store in Cincinnati.** The product codes were represented by "bull's-eye barcodes", a set of concentric circular bars and spaces of varying widths. These barcodes were not pre-printed on the item's packaging, but were labels that were put on the items by Kroger employees. But there were problems with the RCA/Kroger code. It was recognized that the industry would have to agree on a standard coding scheme open to all equipment manufacturers in order to get food producers and dealers to adopt the technology." (Adams, 2010)
Agreement for adoption of standard	1967	"**By 1967 most of the kinks had been worked out, and a nationwide standard for a coding system was adopted. All that**

		remained was for railroads to buy and install the equipment." (Seideman, 1993)
Vision about applications by a scientist within a company *Lack of willingness to invest by company* *Scientist quits and founds a company*	1967	"**Collins foresaw applications for automatic coding far beyond the railroads, and in 1967 he pitched the idea to his bosses at Sylvania. "I said what we'd like to do now is develop the little black-and-white-line equivalent for conveyer control and for everything else that moves," he remembers. In a classic case of corporate shortsightedness, the company refused to fund him. "They said, 'We don't want to invest further. We've got this big market, and let's go and make money out of it.' " Collins quit and co-founded Computer Identics Corporation**." (Seideman, 1993)
Scientist develops technology within a company	Late 1960s	"**Collins continued his work with Automatic Identification technology at Compunetics. Switching to a black and white barcode, the real innovation of his system was the use of a laser beam as a light source. The laser light was smaller, cooler and could be moved back and forth rapidly over the code, giving rise to the terms "barcode scanner" (because the laser would pass over the code many times per second) and "laser line" (the optical illusion of the laser scanning over the barcode). In the late 1960's, Computer Identics installed two of these systems - one in a General Motors plant and the other in the General Trading Company's distribution center in New Jersey. The barcodes held only 2 digits of data - but that was enough to allow pertinent information to be gathered.**" (Reynolds, n.d.)
Technological Advances	1969-early 1970s	"**Meanwhile, Computer Identics prospered. Its system used lasers, which in the late 1960's were just becoming affordable**. A milliwatt helium-neon laser beam could easily match the job done by Woodland's unwieldy five-hundred-watt bulb. A thin stripe moving over a bar code would be adsorbed by the black stripes and reflected by the white ones, giving scanner sensors a clear on/off signal. Lasers could read bar codes anywhere from three inches to several feet away, and they could sweep back and forth like a searchlight hundreds of times a second, giving the reader many looks at a single code from many different angles. That would prove to be a great help in deciphering scratched or torn labels." (Seideman, 1993)
Hallmark 2: First market Introduction (?) (<u>Accepted</u>) *Components being built by hand*	1969	"**In the spring of 1969 computer Identics quietly installed its first two systems – probably the first true bar code systems anywhere. One went into a General Motors plant in Pontiac, Michigan, where it was used to monitor the production and distribution of automobile axle units. The other went into a distribution facility run by General Trading Company in Carlsbad, New Jersey, to help direct shipments to the proper loading-bay doors. At this point the components were still being built by hand;** Collins made the enclosures for the scanners by turning a

		wastebasket upside down and molding fiberglass around it. **Both systems relied on extremely simple bar codes bearing only two digits worth of information.** But that was all they needed; the Pontiac plant made only eighteen types of axle, and the General Trading facility had fewer than a hundred doors." (Seideman, 1993) "Collins continued his work with Automatic Identification technology at Compunetics. **Switching to a black and white barcode, the real innovation of his system was the use of a laser beam as a light source. The laser light was smaller, cooler and could be moved back and forth rapidly over the code, giving rise to the terms "barcode scanner" (because the laser would pass over the code many times per second) and "laser line" (the optical illusion of the laser scanning over the barcode). In the late 1960's, Computer Identics installed two of these systems - one in a General Motors plant and the other in the General Trading Company's distribution center in New Jersey. The barcodes held only 2 digits of data - but that was enough to allow pertinent information to be gathered.**" (Reynolds, n.d.)
Patent Expiration	1969	"Neither Silver nor Woodland made much money on the idea that started a billion-dollar business. That was because they sold the patent to RCA in 1952 for a small sum of money, long before any commercialization of the technology. **The patent expired in 1969, 5 years before the first industry wide use of barcode in grocery stores. It was an invention ahead of its time**." (Adams, 2010)
Formation of a committee to examine proposals for standards – <u>Out of Scope</u>	1970	"Already RCA was moving to assist the industry. RCA executives had attended a 1966 grocery industry meeting where bar-code development had been urged, and they smelled new business. A special group went to work at an RCA laboratory in Princeton New Jersey, and the Kroger grocery chain volunteered itself as a guinea pig. **Then, in mid-1970, an industry consortium established an ad hoc committee to look into bar codes. The committee set guidelines for bar code development and created a symbol selection subcommittee to help standardize the approach.** This would be the grocery industry's Manhattan Project, and Alan Haberman, who headed the subcommittee as president of First National Stores, recalls proudly, "We showed that it could be done on a massive scale, that cooperation without antitrust implications was possible for the common good, and that business didn't need the government to shove them in the right direction." At the heart of the guidelines were a few basic principles. To make life easier for the cashier, not harder, bar codes would have to be readable from almost any angle and at a wide range of distances. Because they would be reproduced by the millions, the labels would have to be cheap and easy to print. And to be affordable, automated checkout systems would have to pay for themselves in

		two and a half years. This last goal turned out to be quite plausible; a 1970 study by McKinsey & Company predicted that the industry would save $150 million a year by adopting the systems." (Seideman, 1993) "Back in the grocery business, a consortium of food chains tasked Logicon, Inc. to make recommendations for the proposal for an industry-wide barcode system and symbology. **By 1969 the Ad Hoc Committee on a Uniform Grocery Product Code was formed, chaired by the President of H.J. Heinz Company, and including members from General Foods, Kroger, A & P, Proctor & Gamble, among others. The Ad Hoc Committee refined competing proposals from technology companies bidding on developing the technology. These companies included RCA, IBM, Singer, Litton and Pitney-Bowes.**" (Reynolds, n.d.) "**In 1969, the NAFC asked Logicon, Inc. to develop a proposal for an industry-wide bar code system. The result was Parts 1 and 2 of the Universal Grocery Products Identification Code (UGPIC) in the summer of 1970. Based on the recommendations of the Logicon report, the U.S. Supermarket Ad Hoc Committee on a Uniform Grocery Product Code was formed.** Three years later, the Committee recommended the adoption of the UPC symbol set still used in the USA today. It was submitted by IBM and developed by George Laurer (see the history at his web site), whose work was an outgrowth of the idea of Woodland and Silver. Woodland was an IBM employee at the time." (Adams, 2010)
Failed attempt for commercialization – <u>Out of Scope</u>	1970-mid1970s	"**Sylvania never even saw profits from serving the railroad industry. Carriers started installing scanners in 1970, and the system worked as expected, but it was simply too expensive. Although computers had been getting a lot smaller, faster, and cheaper, they still cost too much to be economical in the quantities required. The recession in the mid-1970's killed the system as a flurry of railroad bankruptcies gutted industry budgets. Sylvania was left with a white elephant**." (Seideman, 1993)
Towards full commercialization of Industrial Applications – <u>Out of Scope</u>	Early 1970s	"**Computer Identic's triumph proved the potential for bar codes in industrial settings, but it was the grocery industry that would once again provide the impetus to push the technology forward. In the early 1970's, the industry set out to propel to full commercial maturity the technology that Woodland and Silver had dreamed up and Computer Identics had proved feasible**." (Seideman, 1993)
Company develops barcode for another application – <u>Out of Scope</u>	1971	"**At the same time, companies pursued the use of barcodes in industrial and other applications**. In 1971 the Plessey Company developed a barcode scanner and tracking system for library book checkout. The Codabar barcode was developed by Monarch

		Marking Systems around the same time for blood collection and book tracking applications. Intermec developed Code 3 of 9, a barcode that could store alpha-numeric information. All other codes prior to this could only represent numeric digits." (Reynolds, n.d.) "**In 1971 RCA would jolt several industries into action**; before then, the next advances in information handling would come out of the railroad industry." (Seideman, 1993)
Demonstration of a technological system at an industry meeting – <u>Out of Scope</u>	1971	"**In the spring of 1971 RCA demonstrated a bulls-eye bar code system at a grocery industry meeting.** Visitors got a round piece of tin; if the code on top contained the right number, they won a prize. IBM executives at that meeting noticed the crowds RCA was drawing and worried that they were losing out on a huge potential market. Then Alec Jablonover, a marketing specialist at IBM, remembered that his company had the bar code's inventor on staff. Soon Woodland-whose patent had expired in 1969-was transferred to IBM's facilities in North Carolina, where he played a prominent role in developing the most popular and important version of the technology: the Universal Product Code (UPC)." (Seideman, 1993)
Testing – Out of Scope *Hallmark 2: First market introduction (?) (<u>Rejected</u>) – <u>Out od Scope</u>*	1972	"**RCA continued to push its bull's-eye code. In July 1972 it began an eighteen-month test in a Kroger store in Cincinnati.** It turned out that the printing problems and scanning difficulties limited the bull's-eye's usefulness. Printing presses sometimes smear ink in the direction the paper is running. When this happened to bull's-eye symbols, they did not scan properly. With the UPC, on the other hand, any extra ink simply flows out the top or bottom and no information is lost." (Seideman, 1993) "Remember the Silver-Woodland patent purchased eventually by RCA? By attending an industry conference in 1966, executives at that company became convinced that using barcode scanners at check-out was an emerging and lucrative market. **They developed a bullseye symbol and a scanner that was installed and operating in a Cincinnati Kroger store beginning in 1972**. Although the system generated valuable Return-on-Investment data, printing problems with the bulls-eye barcodes and scanning problems limited its usefulness." (Reynolds, n.d.)
Company wins competition for adoption of a standard – <u>Out of Scope</u>	1973	"For a time, such exotica as starburst-shaped codes and computer readable characters were considered, **but eventually the technically elegant IBM-born UPC won the battle to be chosen by the industry**. No event in the history of modern logistics was more important. The adoption of the Universal Product Code, on April 3, 1973, transformed bar codes from a technological curiosity into a business juggernaut." (Seideman, 1993)

A committee representing an industry agreed to adopt a standard developed by a company – <u>Out of Scope</u>	1973	"**IBM won the proposal in 1973, using a barcode developed by George Laurer.** The code was (and is) split into halves of six digits each. The first digit is always zero, the next 5 digits represent the manufacturer of the product, digits 7 through 11 is the product number or SKU, and the last digit is a check digit for validation that the code was read correctly. The code can be scanned in either direction, and didn't have the problems with printing that the RCA bulls-eye code had. The vertical orientation of the code allowed printers to void the excess ink at the bottom of the code, making the top of the code perfectly readable. Joe Woodland, the originator of the patent more than 20 years earlier would play an important role with the IBM team developing the technology that won the bid." (Reynolds, n.d.) "For a time, such exotica as starburst-shaped codes and computer readable characters were considered, **but eventually the technically elegant IBM-born UPC won the battle to be chosen by the industry. No event in the history of modern logistics was more important. The adoption of the Universal Product Code, on April 3, 1973, transformed bar codes from a technological curiosity into a business juggernaut.** Before the UPC, various systems had begun to come into use around the world in stores, libraries, factories, and the like, each with its own proprietary code. Afterward bar code on any product could be read and understood in every suitably equipped store in the country. Standardization made it worth the expense for manufacturers to put the symbol on their packages and for printers to develop the new types of ink, plates, and other technology to reproduce the code with the exact tolerances it requires." (Seideman, 1993) "In 1969, the NAFC asked Logicon, Inc. to develop a proposal for an industry-wide bar code system. The result was Parts 1 and 2 of the Universal Grocery Products Identification Code (UGPIC) in the summer of 1970. Based on the recommendations of the Logicon report, the U.S. Supermarket Ad Hoc Committee on a Uniform Grocery Product Code was formed. **Three years later, the Committee recommended the adoption of the UPC symbol set still used in the USA today. It was submitted by IBM and developed by George Laurer (see the history at his web site), whose work was an outgrowth of the idea of Woodland and Silver. Woodland was an IBM employee at the time.**" (Adams, 2010)
First Market Introduction (?) (<u>Rejected</u>) <u>– Out of Scope</u>	1974	"**On June 26th, 1974, and a 10-pack of Wrigley's chewing gum was the first product logged in a grocery store by a barcoding system using the modern UPC code.** Later that year, the Uniform Grocery Product Code Council became the UPCC (Uniform Product

		Code), which regulates the issue and use of all Universal Product Codes." (Reynolds, n.d.)
First Market Introduction (?) (Rejected) – Out of Scope	1974	"**Barcode is being used since 1970s for the identification of items in service sectors**." (Modgil et al., 2012)