The Role of Pilot- and Demonstration Projects in Accelerating Hyperloop

A MULTI-LEVEL PERSPECTIVE TOWARDS LARGE-SCALE TECHNOLOGICAL TRANSITIONS

MAGLEV AS A CASE STUDY

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MASTER OF SCIENCE IN MANAGEMENT OF TECHNOLOGY in collaboration with:

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MAGLEV AS A CASE STUDY

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"We may perhaps learn to deprive large masses of their gravity and give them absolute levity, for the sake of easy transport."

- Benjamin Franklin, 1780

Acknowledgements

In front of you lies the result of the research project that marks the final part of my master program Management of Technology and my time as being a student at the Delft University of Technology. The emergence of this thesis topic originates from my personal interest the contemporary transportation system at large and its urgent quest to become more sustainable in the nearby future. Along the project, my interest grew for the fascinating role that magnetic levitation transportation technologies, both maglev and hyperloop, could have in creating such a sustainable transportation system. As such, I feel grateful that I got the chance to work in collaboration a frontrunner in the high-tech hyperloop technology; Hardt Hyperloop.

My passion for this field has been a constant source of curiosity, which in the end diverted me from the topic from time to time. Nevertheless, writing this thesis allowed me to apply the knowledge that I obtained throughout my years in Delft. In the end, I am confident that the result of this thesis would not have been possible without the help of some highly motivated persons. Therefore, I owe my gratitude to all that have contributed to the realization and attainment of my master thesis project.

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I am sincerely looking forward to presenting my results on August 29th, 2019.

Hidde Phillip Koerkamp

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Executive Summary

Introduction – The transportation industry is one of the foundations of our modern-day economy. More recently, however, it has become apparent that the contemporary transportation system also has severe drawbacks related to increased air pollution, noise nuisance and traffic congestion. One possible way to address these concerns is to develop a new and advanced mode of transportation technologies that satisfies environmental compatibility through minimal carbon footprints on the one hand, while on the other hand accommodates future high-capacity and high-speed throughput. Magnetic levitation (maglev) was developed during the second half of twentieth century as a contactless transportation technology that levitates, accelerates, and decelerates a vehicle through forces generated by magnetic fields. Although technical and environmental potential were promising, the economic risks and uncertainties to the many stakeholders involved created barriers to successful breakthrough within the incumbent high-speed transportation regime based on conventional high-speed rail and air transportation.

In more recent years, the hyperloop concept was revealed that constitutes a modern advanced maglev technology that is complemented by vehicles running through a low pressure environment. Although hyperloop could induce a large technological transition in the high-speed transportation regime, the development requires significant capital investments to exemplify the technical and economic principles successfully. In this context, the emerging hyperloop innovation system faces the same barriers towards successful commercialization. Although pilot- and demonstration projects are recognized for their central role in advancing new knowledge, surprisingly little academic research has been conducted that analyses the different roles of demonstration projects along different stages within emerging innovation systems.

Research Design – Radical innovations often face a mismatch with established regimes. Especially in large technical systems, such as the transportation system, technological lock-in and path dependency related to the incumbent innovation systems raises barriers to successful breakthrough. Therefore, it is important to understand the build-up processes and their virtuous cycles necessary for emerging innovation systems to obtain enough momentum in order to break out of the niche level. The key within these motors of innovation may be found in the various roles of pilot- and demonstration projects. Although the importance of pilot- and demonstration projects in the innovation process has been illustrated, industry can hardly incur long-term costs for realizing large pilot- and demonstration projects. This difficult challenge together with uncertainty and risks may cause underinvestment at this critical stage in the development process and could ultimately lead to premature deaths of potentially promising technologies.

The idea followed throughout this research is that radical innovations within large technical systems emerge within the context of innovation systems formed by networks of actors, institutions and technologies. The objective of this study is to explore the various roles of pilot- and demonstration projects in order to

accelerate technological innovation system dynamics that could lead to a take-off of the hyperloop technology. In order to fulfil the research objective, the following research question have been defined:

> How could pilot- and demonstration projects accelerate the motors of innovation during the formative stage of technological innovation systems to ultimately induce a large-scale technological transitions?

In order to answer this question, the state-of-the-art literature is examined to conceptualize the role of pilot- and demonstration projects within emerging innovation systems and technological transitions. Secondly, an empirical case study on magnetic levitation transportation technologies is performed to empirically validate the theoretical framework. Finally, the theoretical- and empirical analysis are synthesized to answer the research questions and provide scientific- and practical recommendations.

Theoretical Analysis – The current literature describes the ambiguous role of Pilot- and Demonstration Projects (PDP) through a number of different demonstration projects: lab-scale and industrial-scale demonstration projects primarily aimed at experimenting and reducing technical and preliminary economic uncertainty, and deployment- and auxiliary demonstration projects aimed at exemplifying the technology for commercial purposes. Secondly, the literature on Technological Innovation Systems (TIS) argues that innovation systems emerge during the formative stage through a set underlying build-up processes, labelled as the seven Functions of Innovation Systems (FIS); entrepreneurial activity, knowledge development, knowledge diffusion, guidance of the search, market formation, resource allocation and advocacy coalitions. following the concept of cumulative causation, system functions interact and reinforce each other over time. A set of four characteristic virtuous cycles are labelled as the motors of innovation; the science- and technology push motor, the entrepreneurial motor, the system building motor and the market motor. Third, the literature on Technological Transitions (TT) stresses that successful transitions are the result of processes linking up at three levels, the landscape developments, the socio-technical regime, and the technological niche. The theoretical analysis is concluded by proposing a theoretical framework that explicitly emphasized the roles of pilot- and demonstration projects through an added function labelled as “Pilot- and Demonstration Projects”.

Empirical Analysis – The multi-level perspective is taken as a lens to explore how the Magnetic Levitation Transportation Innovation System (MLTIS) unfolded over time. The Event History Analysis is adopted to analyze the development of system structures and functions over time by relating them to individual events. A sequence of events is constructed and a reconstruction of the historical narrative provided a solid basis for the analysis. The narrative is validated by means of interviews with industry experts. Three episodes within the emerging MLTIS were identified. The first episode (1966-1977) is characterized by the rise of the magnetic levitation technology in an environment where high-speed rail and air transportation were creating the socio-technical system around high-speed transportation. The research and development programs were oriented towards lab-scale pilot- and demonstration activities. The second episode (1978-1996) is characterized by

Germany and Japan working on alternative magnetic levitation transportation technologies through a different set of pilot- and demonstration activities. Although the high-speed transportation regime is expanding, developments at the landscape level put the regime on pressure and create an early window of opportunity. The third episode (1997-2012) is characterized by early commercialization efforts from both technologies. The pilot- and demonstration activities shifted from technological demonstration towards public demonstration activities. Although technological readiness was achieved in both development processes, the majority of the proposals was declined because of a lack of economic demonstration activities and feasibility.

Results and Conclusion - The case study analysed the virtuous cycles of the system functions that were observed during the three episodes in terms of structural strengths, weaknesses and impacts. During the first episode, the system functions began to emerge slowly and pilot- and demonstration activities were predominantly concerned with technical experimentation focusing on reducing technical feasibility on a laboratory-scale to create the first expectations. The second episode is characterized by the further strengthening of the virtuous cycles. Now, pilot- and demonstration activities are initiated at industrial scale for preliminary economic experimentation. Finally, during the third episode, is characterized by the early commercialization efforts of the magnetic levitation technology as technology developers initiated technological deployment demonstration projects. The virtuous cycles that were observed during the empirical case study and corresponded with the conceptual framework that was created.

In order to answer the research question, the science and technology push motor is strengthened by emphasizing the pilot- and demonstration function through lab-scale pilot- and demonstration projects. More specifically, these demonstration projects are focused on basic research and demonstrating the technical feasibility. With limited resources necessary, the positive outcomes of these demonstration projects could induce a first virtuous cycle by reducing the initial technological uncertainties and accelerate the virtuous cycles within the first motor of innovation. Second, the entrepreneurial motor is strengthened by incorporating the demonstration function related to industrial-scale demonstration projects, thereby focusing on technical and preliminary economic feasibility on a commercial scale. Positive results are diffused, reinforce positive expectations and attract additional firms and research institutes join the projects to invest in the project, thereby contributing to the first expansion of the research and development program. Third, the system building motor is strengthened by emphasizing the pilot- and demonstration function through deployment demonstration projects. More specifically, these demonstration projects are focused on demonstrating the technical and economic feasibility of the entire innovation system embedded in the incumbent regime. The deployment demonstration is particularly important to attract early adopter support for the product at large before a first commercial system can be brought to the market.

Keywords: Pilot- and Demonstration Projects; Technological Innovation Systems, Motors of Innovation; Technological Transitions; Landscape Developments, Niche Developments; Regime; Maglev; Hyperloop.

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Abbreviations

EDS	Electrodynamic Suspension
EMS	Electromagnetic Suspension
FIS	Function of Innovation Systems
HLS	Hyperloop Lane Switch
HSR	High-Speed Rail
HTT	Hyperloop Transportation Technologies
IABG	Industrieanlagen-Betriebsgesellschaft
LTS	Large Technical Systems
MLP	Multi-Level Perspective
MLTIS	Magnetic Levitation Transportation Innovation System
NIS	National Innovation System
IS	Innovation System
PDP	Pilot- and Demonstration Projects
R&D	Research and Development
RIS	Regional Innovation System
SIS	Sectoral Innovation System
SMT	Shanghai Maglev Train
SNM	Strategic Niche Management
TC	Technological Change
TIS	Technological Innovation Systems
TNEM	The Northeast Maglev
TT	Technological Transition
TVE	Transrapid-Versuchsanlage Emsland
UKU	United Kingdom Ultraspeed

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PART A – INTRODUCTION

1. Introduction

1.1. Background

The transportation industry is one of the foundations of our modern-day society. As major part of today's economy is devoted to the transportation of passengers and freight, the revolution in the transportation system has brought society substantial benefits over the last decades. Technological progress in vehicles and infrastructures has facilitated the globalization of the world economy, reduced trip times and provided more comfort at a cheaper price. More recently, however, the movement with respect to anthropogenic climate change has triggered a new debate on the drawbacks of the traditional transportation system (Dimitriou & Gakenheimer, 2011). The enormous increase in mobility patterns and the ability to travel large distances comes at a costs. Modern societies are increasingly encountering environmental and political problems related to increased oil dependency, air pollution, noise nuisance and traffic congestion.

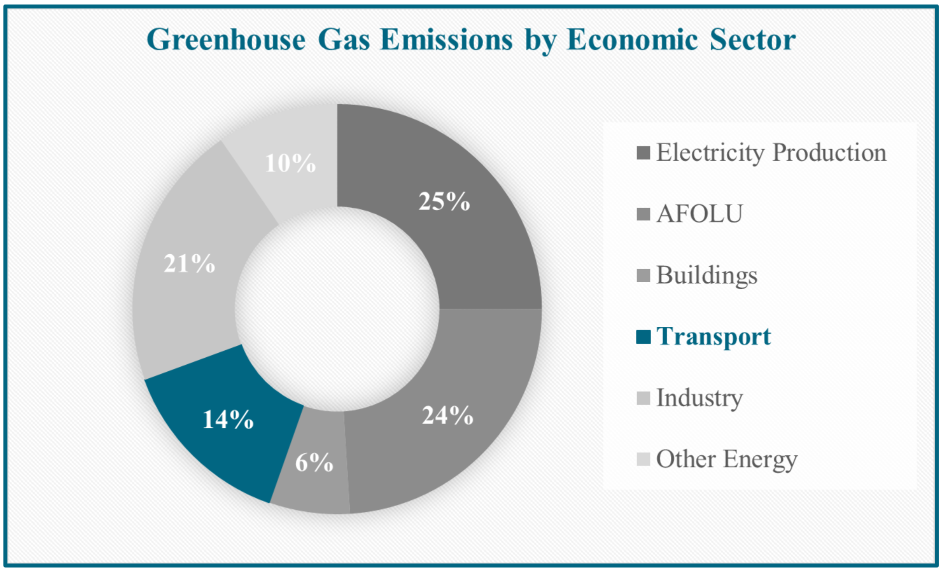


Figure 1 - Greenhouse Gas Emissions by Economic Sector (IPCC, 2014)

The global transportation sector is responsible for the 14% of the total global greenhouse gas emissions (Figure 1). Successful achievement of the ambitious climate change mitigation targets – on which 196 countries agreed upon in Paris in December 2015 – will require near complete decarbonization of developed countries' economies before the next century (Rogelj, 2015). The necessity and urgency to reform the mobility industry can be demonstrated by the fact that current modes of transportation often have severe adverse side effects, mostly related negative environmental impact of the transportation industry on the environment. The contemporary transportation consists of four unique modes and each have their distinct adverse impacts. Road- and water transport are relatively inexpensive but nevertheless time-consuming and not environmentally friendly, thereby contributing to the depletion of fossil fuel reserves and polluting the atmosphere. In contrast, air travel is fast but also expensive and damaging from an environmental perspective whereas rail transport is relatively fast and environmentally sound but requires enormous sunk infrastructure costs.

In order to address these concerns, a quantum leap in transportation technologies is necessary. This entails the development of advanced high-speed transportation technologies that satisfies environmental compatibilities through minimal carbon footprints on the one hand, while on the other hand supports high capacity throughput at high speeds to accommodate future mobility demand. Despite governments stimulating the use of public transport to cope with congestion and the greenhouse gas emissions, the UK and the Netherlands projected the annual congestion costs of GBP 30 billion in 2010 and €3.7 billion in 2017, respectively (Kennisinstituut voor Mobiliteitsbeleid, 2017). In order to overcome these interrelated challenges of the current transportation system, a future mode of transport would therefore ideally be faster, safer, cheaper and environmentally sound.

1.2. Magnetic Levitation Transportation

The concept of magnetic levitation for transportation, or maglev, has been around for some time. In the early 1900s, Robert Goddard and Emile Bachelet envisioned a frictionless train. Rather than using conventional wheels-on-rail technology, a maglev transportation system was proposed as a contactless transportation technology that lifts the vehicle from its track or guideway and accelerates and decelerates by the magnetic forces generated between the onboard (super)conducting magnets and ground coils in the guideways.

Since late 1960s, research and development on high-speed maglev systems has been carried out on a global scale to accommodate the gap between conventional rail- and air transportation. Early feasibility studies showed that the technological and economic potential of high-speed magnetic levitated transportation technologies is enormous (Elhorst & Oosterhaven, 2008; Luguang Yan, 2008). For instance, maglev systems have no moving parts as magnets in the guideway control both speed and stability, thereby reducing maintenance costs drastically. Moreover, maglev is operating with lower sound emissions and smoother compared to conventional trains, resulting in higher operating speeds at less noise nuisance.

Figure 2 - Shanghai Maglev Train

Figure 3 - Shinkansen L0 Series

Nevertheless, the incremental benefits were often hard to justify against costs and risks and embedding maglev systems within the existing high-speed transportation landscape proved far from straightforward. Despite high expectations on environmental- and economic efficiency, maglev systems have not been successfully adopted on a global scale. The German-developed Shanghai Maglev Train (SMT) remains the only operational system today (Figure 2) and the Japanese Chuo Shinkansen is set to open no earlier than 2027 (Figure 3).

Where advanced transportation technologies are concerned, decades often elapse between discovery of technological ideas in principle and the possibility of their successful application. Over fifty years have passed and maglev transportation has not been able to compete on a large scale with other modes of high-speed transportation. Instead most proposals were abandoned, mostly in favor of convention high-speed rail. This especially holds true in situations where conventional high-speed rails or high-ways exist or were proposed. As maglev systems are not compatible with conventional infrastructure systems and therefore have to be designed as standalone transportation system. Therefore, maglev transportation faced severe barriers in positioning itself in the transportation market. A small market niche emerged as the world's first commercial low-speed maglev system opened in Birmingham between 1984 and 1995. Despite its popularity, it was dominated by unreliable services and expensive maintenance (Hall, 2018). The incremental estimated benefits of maglev technology are often hard to justify against the extra costs and risks. The energy required to levitate the vehicle is typically relatively small compared to the overall energy consumption. The majority of the required energy is needed to overcome the drag, which for maglev technology only consist of air resistance.

1.3.The Next Generation: hyperloop

In 2013, Elon Musk, most famously known as being the co-founder of revolutionizing high-tech corporations SpaceX and Tesla, openly criticized the approval of a new high-speed rail transportation system in California and alternatively championed his vision on the next generation levitated transportation technology what could potentially become the design of the Hyperloop (Musk, 2013). Although conceived as groundbreaking by many, the Hyperloop is derived from the vactrain concept and involves a ground-based, high-speed transportation system able to carry large volumes of passengers and cargo. Capsules, or pods, travel through partly evacuated tubes, thereby further decreasing air resistance and increasing operational speeds. Nevertheless, Hyperloop, just as the maglev technology, is a capital-intensive project. So far, various components of the Hyperloop system have been demonstrated on a low Technology Readiness Level (TRL), see Appendix A. But to bring hyperloop from the TRL-3/4 towards commercialization requires significant investments and demonstrations before the first commercial system is operational. In this light, Hyperloop faces similar barriers as maglev, hampering successful commercialization.

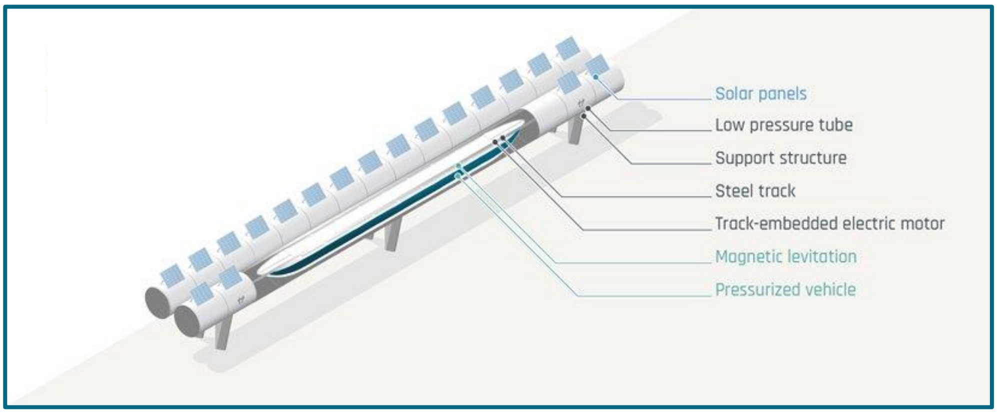


Figure 4 - Hyperloop System Breakdown (Hardt, 2019)

The Hyperloop is a proposed mode of ground-based high-speed and sustainable transportation for carrying large volumes of passengers and freight that has the potential to become the most disruptive innovation in transportation since mass commercialization of the aviation industry. The system consists of tubes above or underground containing a partially evacuated, low-pressure environment to minimize air resistance through which a capsule travels at transonic speeds reaching up to 1200 kilometers an hour. The pods travels on top of an air bearing by means of magnetic levitation in order to achieve a low-friction suspension and is accelerated through an external linear induction motor, providing periodic reboosts to maintain operational speeds.

Hyperloop could potentially bring certain benefits compared to existing modes of transportation, i.e. reduced lower costs, more energy efficient and thus a lower environmental footprint and a relatively easy infrastructure (Figure 5). Hyperloop ideally connects high traffic destinations less than 1500 kilometers apart, being a high potential solution to cover the business- and commuter segment of the transport industry. Above that point restoring supersonic air travel is considered to be both faster and more efficient. Rather than developing and protecting the technology solely, the concept was made publicly available to encourage those interested to contribute to the research and development process and bring it from concept to reality. This open source innovation approach allows individual firms to gain valuable knowledge-creating options by tapping into knowledge assets beyond their own corporate boundaries (Grand et al., 2004). Nevertheless, successful commercialization of hyperloop technologies faces similar challenges to the maglev transporation system.

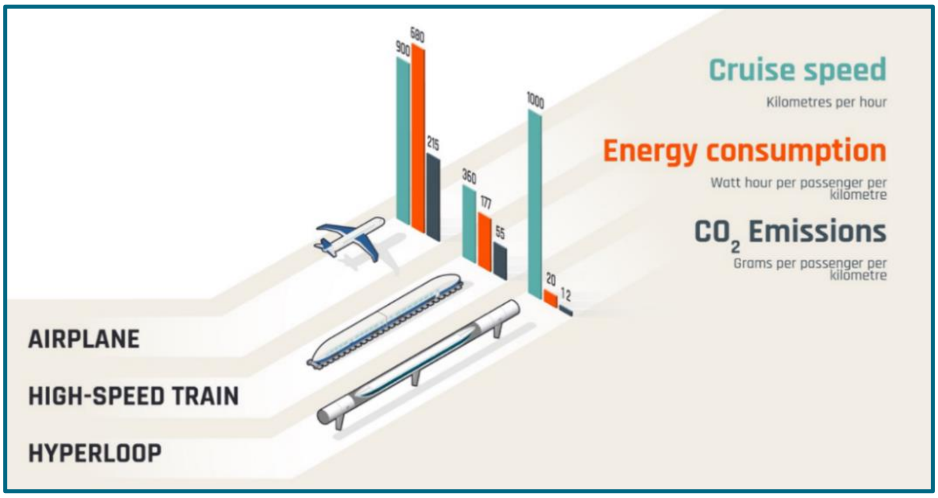


Figure 5 – Comparison between High-Speed Transportation Modes

In 2016, the first operational test in the SpaceX test tube were conducted and a demonstration facility was constructed to support a university competition. The Hyperloop development and technological expectations are rapidly gaining momentum. Although future prospects remain highly uncertain, the emergence of a competitive state-of-the art technology market resulted in an array of commercial parties working on the Hyperloop technology and attempting to be the first to deliver a successful and reliable commercial service. Currently, Hardt (Netherlands), Zeleros (Spain), Hyperloop One (USA), Hyperloop Transportation Technologies (USA) are some key players further developing the technology.

In June 2017, the first European Hyperloop demonstration project was revealed in the Netherlands. It consists of a 30m full-scale tube. Most of these companies are now searching for opportunities to establish a pilot- and demonstration projects to bring the technology a step closer to commercialization. The next step for the technology to be taken is bringing the technology to the next TRL, including design verifications, testing of track turns, high-speed switches, pressurized pods as well as safety measures and -procedures. The Netherlands has an excellent track record in facilitating innovation and the value added by the test facility will contribute to the Dutch knowledge infrastructure. Its ambition is to further strengthen this position and to create a knowledge infrastructure around the Hyperloop technology. Following the results of a preliminary quick scan in 2016, the Ministry of Infrastructure and Water Management requested a consortium of TNO, BCI, VINU and Arup to perform a technical feasibility study to examine the functionality and potential location of a test facility in the Netherlands. The report recommended to build a jointly public-private financed test track of three kilometer which could ultimately be extended to a first commercial route once proven successful. However, to date a clear and suitable cooperative strategy to practically establish a test facility is missing and the technology development is hampered. Hence at this stage the technology maturity remains within the experimental phase and bringing the technology from successful initial tests to a full-scale commercial deployment remains a big hurdle yet to be taken.

1.4. Large Technical Systems

From a more theoretical perspective, Large Technical Systems (LTS), such as the transportation system, cannot be understood as a set of discrete heterogeneous technological artefacts (Hughes, 2012). Rather, they have to be seen as complex technological systems embedded in a powerful context of both public- and private institutions (Unruh, 2000). These networks are of enormous proportions and stretch beyond geographical borders, such as railroad-, electricity-, and telephone networks (Hughes, 1986). It is because of their complexity that modern-day industrial economies have been locked-in through a process of technological and institutional co-evolution, driven by strong path dependencies and increasing returns-to-scale (Unruh, 2000). This particularly represents a problematic setting for alternative and more sustainable high-speed transportation technologies to break through as they have to compete with the incumbent transportation system dominated by high-speed rail and air transportation. More specifically, these LTS have a certain degree of rigidity as they are fully embedded in society. The incumbent systems already have benefited from long periods of operation, thereby benefiting from positive reinforcements in the form of increased efficiencies, scale economies, network externalities and the accumulation of knowledge.

1.4.1. Innovation Systems

The development of radical innovations within LTS is related to the build-up of a set of structural elements and their networks over time. In a broader sense, technological change can be understood as the process of technology development in interaction with the socio-technical system consisting of networks of actors, institutions and technologies (Geels, 2002). Despite the nature of innovation and the rate of technological change differ from industry to industry, early research widely acknowledged its contribution to long-term economic growth (Schumpeter, 1942; Solow, 1956). Hence there exist a strong need to influence both the speed and direction of innovation and technological change. In order to make technological change sustainable, innovation as such appears to be insufficient and changes in the social regimes – part of the wider Innovation System (IS) - are inevitable. The need for a thorough understanding of its change processes as the emergence of new innovation systems or changes in incumbent innovation systems co-evolve with the process of technological change (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007).

Technological Transitions (TT) and system innovations are lengthy and complex processes that at the current pace take too long. Modern societies put too much effort in stimulating research and development, while in order to accelerate TT efforts should focus on the demand side of innovation. For radical innovations to be successful they have to overcome considerable barriers. It is these kind of innovation processes where government support and protected niche market for stimulating private investments are necessary (Smith & Raven, 2012). In addition, TTs do not only involve technological changes, but also changes in user practices, regulation, industrial networks, infrastructure, that is, changes in the entire socio-technical regime. The system innovation theory describes innovation as the transition from one socio-technical regime to another (Geels & Schot, 2007).

The multi-level perspective argues that the stability of incumbent social-technical regimes is the result of strong linkages between the elements of the regime, originated by activities of social groups who reproduce them. These regimes create technological trajectories and create stability as they guide the innovative activity toward incremental improvement along the way. Within this perspective, the successful development and implementation of the hyperloop technology poses a major challenge as extensive cost reductions are necessary, technological breakthroughs are required and a complete alteration of the transportation infrastructure is necessary. Research and development have been constrained by technical drawbacks, high research- and capital costs, and the technological lock-in and path dependent character of the transportation industry. Although plenty of research has been devoted to LTS, a more theoretical approach to understand the role of pilot- and demonstration projects in accelerating technological transitions is needed.

1.4.2. Valley of Death

Although the importance of pilot- and demonstration projects in the innovation process has been illustrated {Frishammar et al, 2015}, industry can hardly incur long-term costs for realizing large pilot- and demonstration plants. This difficult challenge together with uncertainty and risks may cause underinvestment at this critical stage in the development process and could ultimately lead to premature deaths of potentially promising technologies (Nemet, Zipperer, & Kraus, 2018). Experience shows that the majority of technologies developed in laboratories fail to make it to the market, that research, development of new knowledge takes several decades, and that many stakeholders engaging in innovation process struggle with the so-called "Valley of Death" (Moore, 1991).

The valley often arises due to the lack of private support, insufficient access to capital funding, minimal public support and the absence of regulation. It is often a mix of underestimated costs, overestimated future revenues, undervalued environmental impacts and overvalued economic development effects that makes the development process of LTS so inherently uncertain and exceptionally risky (Flyvbjerg et al., 2003). In order to successfully secure resources along the innovation value chain, project finance must be supplemented with additional funding programs in order to implement and commercialize potentially valuable technologies (Markham, 2002).

Accordingly, technological expectations serve as major determinants for guiding the direction and adoption rate of technological change (Alkemade & Suurs, 2012). Positive expectations could attract powerful stakeholders and aligning their interests could create improved legitimacy to the technology (Hekkert et al., 2007). These processes could even help create a protective niche in which the technology is more likely to be positively evaluated (Smith & Raven, 2012). Moreover, expectations play an important role in mobilizing resources such as knowledge, funding and labour. Collective expectations are also able to mitigate high uncertainties levels perceived by stakeholders and hence are pivotal in attracting actors to the technological innovation system and to stimulate the other key processes in innovation-development processes. Evidently, its relevance is strongest in the early phases of the development process which are accompanied by high levels of uncertainty with respect to future performance and potential applications (Anderson & Tushman, 1990). The technology developer heavily relies on these collective expectations: the stronger and more credible the expectations about the technology and its potential capabilities are, the higher its chance for both public- and private support (Bakker et al., 2012). The expectations on emerging technologies are dynamic and often follow a typical pattern with alternating phases of hypes and disappointment (Van Lente, 1993). These hype cycles arise when a sharp rise in positive expectations is followed by a peak of inflated expectations and a though of disillusionment, that is, a sudden increase in negative expectations (Kriechbaum et al., 2018).

Following the introductory section, emerging innovation systems will pass through a so-called formative stage before being subjected to market environment. During this stage, in addition to the technologies being advanced, actors are attracted, networks are created and institutions are developed. Nevertheless, especially for Large Technical System, the build-up processes tend to become stuck in the production of feasibility studies and small-scale laboratory experiments. Moreover, practical experience from historical high-speed maglev development shows an excessive focus towards achieving technical feasibility, but a lack of understanding how such an advanced transportation system could be embedded within the existing transportation regime and landscape (Geerlings, 1998). Radically new technologies develop within the context of a technological innovation system that is made up of networks of actors, institutions and technologies. These systems do not come into practice overnight but are created as the result of build-up processes in which actors are attracted, institutions are created and networks are formed. This formative stage is based on the notion of cumulative causation, which implies that the fulfilment of system functions could result in a virtuous cycles, thereby creating positive feedback loops that accelerate the build-up processes.

2. Research Design

2.1.Introduction

The second chapter contains the research design. First, the practical and theoretical issues that logically follow from the introduction are described in the problem statement. Consequently, the research objective is defined and the research questions are formulated. Thereafter, the contribution and relevance of fulfilling the research objective from both a scientific and practical point-of-view are discussed. Then, the research approach delineates the procedure and method followed to arrive at an answer for the research questions to satisfy the research objective. Finally, the outline for the remainder of this document is provided.

2.2.Problem Statement

Following the introductory section, radically innovation within Large Technical Systems (LTS), such as maglev or hyperloop, often face a mismatch with established socio-institutional frameworks as regulations, infrastructures, user practices are thoroughly linked and aligned to existing technologies. Nevertheless, these socio-technical configurations rarely remain closed for good as transformations in the landscape level may put pressure on the incumbent regime, thereby providing a window of opportunity for radical innovations. Now the key is to understand how emerging innovation systems at the niche level gain enough momentum to utilize that window of opportunity in order to break out of the niche level and induce a technological transition.

The answer could be found in the ambiguous roles that pilot- and demonstrations projects (PDP) have within the innovation development process. PDPs could constitute bridges between generating basic knowledge and technological breakthroughs on the one hand, and industrial applications and commercial adoption on the other hand. Radically new technologies are in bold need for these PDPs to test for technical-, economic-and organizational viability to facilitate early commercialization. Moreover, as PDPs may take different roles as the IS development progresses, its implications are far-reaching along the entire innovation system development as they attract more stakeholders and accelerate the overall build-up processes.

However, the establishment of large-scale PDPs projects is confronted with two major self-fulfilling prophecies. First, PDPs require substantial capital-intensive investments. The industry is often reluctant or incapable to fully commit to these long-term costs as risks and uncertainty with respect to future market prospects and returns-on-investment are severe. Although the technological and economic risks could be mitigated through disseminating the results of PDP activities, the lack of capital investment limits this. Secondly, the public sector expects private industry to support the innovation process before stepping in. On the contrary, private industry perceives public support as a crucial metric for market potential and are often reluctant to commit their support without it.

As a result, often highly promising innovations are prone to weak incentives for investment from both public- and private participants and without PDP therefore fail to make it to the market. Hence, to overcome this impasse, increased knowledge on the various roles of PDPs is needed. Although PDPs are recognized for their central role in advancing new knowledge, surprisingly little academic research has been conducted that analyses the its changing roles along different stages in emerging IS. The conceptions are broad, fragmented and found in various research disciplines. Therefore, in order to overcome this pressing issue, a deeper and more holistic understanding of the role of PDPs within the formative stage of IS is needed.

2.3. Research Objective and Questions

In retrospect of the problem statement, the main idea followed throughout this research project is that radical innovations in LTS emerge within the context of IS, assembled by actors, institutions, technologies and their networks. Therefore, this research ultimately tries to contribute to the overall understanding of technological change in large technological systems and, more specifically, to the central contribution of PDPs in accelerating configuration processes emerging IS. Therefore, the research objective is formulated as follows:

"The general objective of this research is to contribute to the understanding of the role of Pilot- and Demonstration Projects within emerging Innovation Systems."

In doing so, it will improve the theoretical understandings of the dynamics of technological trajectories around large technical systems and integrate the role of pilot- and demonstration projects in developing technological innovation systems. Provide practical lessons for the modern-day development processes of the most recent generation of magnetic levitation transportation technologies, the hyperloop. Moreover, the results will provide avenues for further research in accelerating radical innovations within large technical systems. In order to fulfil the research objective, the following research question have been defined:

RQ-1 How could pilot- and demonstration projects accelerate the motors of innovation during the formative stage of technological innovation systems to ultimately induce a large-scale technological transitions?

The research questions are complex and cannot be answered directly. In order to provide clear and complete answer to the research question, it is decomposed into the following set of sub research questions that will support the answer to the main research questions:

SQ-1 How does the state-of-the-art literature describe pilot- and demonstration projects?

SQ-2 What the role of pilot- and demonstration projects within the emerging magnetic levitation transportation innovation system?

SQ-3 How does results from the empirical analysis compare to the theoretical analysis?

SQ-4 What are the practical implications to the hyperloop development?

2.4. Contribution and Relevance

The results of this thesis will contribute to the existing knowledge base from a scientific- and practical point-of-view. From a scientific perspective, the main contribution of this thesis reflects to view that the TIS approach is basically a growth model based on the concept of cumulative causation. This particular view suggests that system functions interacting and reinforcing each other over time might successfully support the build-up processes of an innovation system.

2.4.1. Scientific Relevance

Although scientific proceedings that study functions of innovation systems and their mutual interactions are not new (Bergek, Hekkert, & Jacobsson, 2008), so far, no attempt has been made to specifically address the role of PDPs in attracting actors, forming industrial networks and developing institutions to accelerate the overall IS development. Therefore, it is necessary to synthesize the different research fields and generalize the findings to establish a more theoretical understanding of the role of PDPs in the emergence of IS and TT.

The results of this research not only includes lessons from the unsuccessful story of earlier magnetic levitation technologies, but also tests and expands the FIS approach and the MLP by providing complementary insights to previous work from Geels (2005) and Hekkert et al. (2007). The analysis provides several lessons to take into account when for the acceleration of system innovations and technological transitions. In addition, scholars focused primarily on renewable energy. Although regime shifts within LTS is are studies within the transition literature, it remains an underexposed topic within other industries. The role of public support in stimulating private investment has been thoroughly examined. PDPs have been highlighted in Strategic Niche Management (SNM) and Technological Innovation System (TIS) literature, but nevertheless not extensively elaborated (Hellsmark et al., 2016). However, little academic knowledge is available about the role of PDPs in bringing radical innovation within LTS to the market and a coherent strategy for managing pilot- and demonstration plants is lacking (Hendry, Harborne, & Brown, 2010). Hence, additional knowledge about the roles and organization of demonstration projects in innovation-development process is needed.

2.4.2. Practical Relevance

Aside from a scientific contribution, this research is also practically relevant. As pointed out in the introduction, the successful development of a future hyperloop system is dependent on the realization of PDPs. Therefore, the results from this research will also be of value to Hardt Hyperloop. The start-up was founded in 2016 after it won the first SpaceX Hyperloop competition. In June 2017, the company revealed the first European Hyperloop 30m full-scale demonstration project in Delft. In August 2017, the Ministry of Infrastructure and Water Management requested a consortium led by TNO to perform a feasibility study to examine the functionality and potential location of a demonstration project in the Netherlands. The report recommended to build a jointly public-private financed test track of three kilometre which could ultimately be extended to a first commercial route once proven successful. Hence at this stage the technology maturity remains within the experimental phase and bringing the technology from successful initial tests to a full-scale commercial deployment remains a big hurdle yet to be taken. In June 2019, Hardt Hyperloop presented the breakthrough it had achieved by demonstrating the world's first Hyperloop Lane Switch (HLS) technology. Especially since it has only been demonstrated on low-speeds, the need for a high-speed testing pilot- and demonstration facility is essential to realizing a full-scale high-speed pilot- and demonstration project.

2.5.Research Approach

The nature of this research approach broadly falls into two parts: a theoretical- and an empirical part.

2.5.1. Theoretical Analysis

The theoretical analysis in which the state-of-the-art literature is examined. First, the literature describes the ambiguous role of Pilot- and Demonstration Projects and identifies a number of different demonstrations: small-scale and industrial-scale demonstrations primarily aimed at reducing technical and economic uncertainty, and deployment and auxiliary technology demonstration projects aimed at exemplifying the technology for commercial purposes. Secondly, the literature considers the Technological Innovation System approach to understand how innovation system emerge through a set underlying processes necessary for within the formative stage of emerging innovation system. The processes are labelled as the seven Functions of Innovation Systems; Entrepreneurial Activity, Knowledge Development, Knowledge Diffusion, Guidance of the Search, Market Formation, Resource Allocation and Advocacy Coalitions. Following the concept of cumulative causation, system functions interact and reinforce each other over time. A set of characteristic virtuous cycles are labelled as the Motors of Innovation; the Science- and Technology Push Motor, the Entrepreneurial Motor, the System Building Motor and the Market Motor. Third, the literature stresses that Technological Transitions are the result of processes linking up at three levels, the landscape developments, the socio-technical regime, and the technological niche. The theoretical analysis is concluded with a proposed theoretical framework that explicitly emphasized the various roles of pilot- and demonstration projects: an eight function Pilot- and Demonstration Projects. Finally, a theoretical framework is constructed that connects the three literature streams and proposes a new function labelled as “F8 Pilot- and Demonstration Projects”.

2.5.2. Empirical Analysis

Consequently, the empirical analysis examines the history of the development and early commercialization efforts of magnetic levitation transportation technologies in order to empirically validate the theoretical framework. The case study is performed according to the Event History Analysis in which a sequence of events is related to system functions. Finally, the last part synthesizes the theoretical- and empirical analysis in order to answer the research questions, provide scientific- and practical recommendations as well as present avenues of future research agendas.

2.6.Research Structure

The remainder of this thesis is structured according to the following chapters:

Chapter 2. Pilot- and Demonstration Projects in the Literature

The second chapter presents the theoretical analysis by reviewing insights on the role of pilot- and demonstration projects within the dynamics of technological innovation systems, and more specifically, the motors of innovation within the multi-level perspective on technological transitions. The results are conceptualized and a new function on pilot- and demonstration activities is proposed.

Chapter 3. Method for Case Study

The third chapter describes how the system structures and -functions can be identified and measured within a longitudinal case study. This approach is called the Even History Analysis. The origins of the Event History Analysis are discussed and the data gathering and processing methods are discussed.

Chapter 4. A High-Speed Maglev Case Study

The fourth chapter represents the empirical analysis by reviewing the role of pilot- and demonstration projects within the emerging innovation system of maglev transportation technologies. The multi-level perspective around high-speed transportation is reconstructed, the build-up processes that took place in the technological niche are analyzed and their impact on the motors of innovation are identified.

Chapter 5. Discussion

The fifth chapter presents a synthesis and discussion of the results from the empirical case study in comparison to the theoretical analysis. The relative structural strengths and weaknesses that supported these build-up processes are classified as well as the impact these processes had on the structural reconfiguration processes.

Chapter 6. Conclusions and Recommendations

The final chapter will be providing final conclusions based on the case study results. Limitations as well as recommendations for future research will be provided.

PART B – THEORETICAL ANALYSIS

3. The Role of Pilot- and Demonstration Projects in Technology Development

3.1. Introduction

The third chapter contains the theoretical analysis on the role of pilot- and demonstration project in technology development. The objective is to review the state-of-the-art literature on the role of pilot- and demonstration projects within different fields of innovation literature. The results will provide a firm foundation which can be used as building blocks for the remainder of this thesis. As a start, the second section introduces the role of Pilot- and Demonstration Projects (PDP). Therefore, the third section introduces the Technological Innovation System (TIS) approach and the role PDP activities have on supporting system functions. Additionally, section four describes the Strategic Niche Management (SNM) approach as part of a multi-level perspective on Technological Transitions (TT). The chapter is concluded by combining the different literature steams in order to construct a theoretical framework that conceptualizes the various roles of pilot- and demonstration projects throughout the innovation-development process.

3.2. The Role of Pilot- and Demonstration Projects

As a start, the literature on PDPs in technology development is reviewed. The first section retrieves a general definition of PDPs. The second section discusses the different purposes of these demonstration projects whereas the third section provides a distinction between six different demonstration projects.

3.2.1. Defining Pilot- and Demonstration Projects

Pilot- and Demonstration Projects (PDP) can be an effective tool in the discovery and development of radically new technologies as they may assist in crossing the chasm between fundamental- and applied research on the one hand, and commercial deployment and adoption on the other. It is a crucial instrument when it is not intrinsically obvious that a radically new technology shows its intended performance in a real-world full-scale environment, or when its expected benefits must be proven and seen by early adopters to be accepted (Brown et al., 1993). Therefore, demonstration projects are most crucial during the early stages of the development process when actors do not have reliable information about the technological performance. Demonstration projects are small- to full-scale applications in which radically new technologies are tested, verified and optimized under simulated or real-life conditions. It generally involves one of the early stages of the technology development life cycle between the laboratory research and early commercial adoption (Baer, Johnson, & Merrow, 1976). When effectively managed, demonstration projects constitute a powerful and crucial tool for bringing new technologies to the market (Brown, Livesay, Lux, & Wilson, 1993). Although the definitions of demonstration projects are heterogeneous, there is consensus that its objective goes beyond pure technological challenges (Myers, 1978; Macey & Brown, 1990). Whereas small-scale prototype testing in laboratories often only concentrates on providing technical feasiblity and early estimates of cost schemes, large-scale technology demonstration projects generally also focusses on market demand, institutional barriers, and other non-technical factors. Its goal is to stimulate market penetration by providing information to all stakeholders involved. Major factors related to the success of demonstration projects, those that show relative economic advantage, include the extent to which technological issues are worked out, the extent to which costs and risk are shared with all stakeholders, the extent to which demonstrations are supported by private participants, the existence of socio-technical systems for commercialization, and the absence of time constraints (Baer et al., 1976).

As acknowledged by Frishammar et al. (2015), the literature on technology demonstration projects is broad, fragmented and found in multiple research domains. Therefore, existing literature on technology demonstration projects is categorized into three literature streams. First, the engineering- and natural science research literature emphasizes the experimental character of technology demonstrations and focuses on technical challenges involved in the verification processes and up-scaling efforts of new technologies. Second, in the technology- and innovation management literature stream, improved understanding of technology demonstration projects as tools for learning processes and arenas for stakeholder collaboration imply that, beyond pure technical challenges, also economic and organisational challenges must be addressed to move a technology closer to commercialization. Third, the innovation systems literature is the most comprehensive literature stream and consider the dynamics of technological change and therefore examine role of technology demonstration projects from the wider innovation system perspective, including the role of public support and innovation policy in bringing technologies to the market. Beyond addressing technical challenges, the innovation system approach also emphasizes market- and network formation, the creation of new value chains, alignment of institutions and public acceptance as valuable roles in assisting the wider socio-technical system. It is in this context that PDPs could serve different purposes and take on different roles.

3.2.2. Purposes of Technology Demonstration Projects

The first publicly-financed demonstration projects originate from the mid-1950s, when the US supported engineering prototypes of powerplants. Baer et al., (1976) were among the first to pose an analytical framework in order to better understand the contribution of pilot- and demonstration projects in the technology development process. In doing so, they examined the successful- and unsuccessful outcomes of demonstration projects. Although the ultimate purpose is to accelerate commercialization and large scale diffusion, generating new information with respect to the technological performance in a real-world environment is crucial in order to reduce uncertainties prior to decision-making processes by potential adopters and other relevant participants. Hendry et al. (2010) also underpin the different roles of demonstration projects in addressing what they call the “uncertain middle” phase and present an analytical framework to elaborate on the roles of publicly funded pilot- and demonstration plants in the long-term technological development of radically innovations. Much of the early research made a clear separation between technical experimentation and promoting market diffusion and commercialisation.

In this context, Palage et al., (2019) differentiate between different roles of demonstration projects in the innovation system. First, experimental demonstration projects primarily aim to test the technical viability of the technology and progress towards an optimal design. Second, exemplary demonstration projects try to demonstrate the value of the technology to potential early adopters, thereby creating awareness and legitimacy and hence reducing market- and institutional risks. In addition to Baer et al. (1976), a study conducted on behalf of the U.S. Department of Energy also supports the claim that demonstration projects serve various purposes (Myers, 1978). On the one hand, technical demonstrations are undertaken to demonstrate whether the technology, even though proven in a small-scale laboratory environment, is also technically viable in a full-scale operational environment. On the other hand, commercial demonstrations are performed to demonstrate the appropriateness of a technology to potential early adopters, investors and regulators. It is evident that both demonstrations have their differences in terms of their functionality and operability **Error! Reference source not found.**.

	Technical Demonstrations	**Commercial Demonstrations**
Technology Demonstration Objectives	Investors	Potential Adopters
	Experiments	Examples
	Low Visibility	High Visibility
	Quantitative Control and Evaluation	Sufficient Control for Credibility
	Simulated Pertinent Environment	Fully Operational Environment
	Small-scale	Full-scale

Table 1 - Technical- and Commercial Demonstrations (Myers, 1978)

Beyond technical experimentation, the demonstration projects also include economic experimentation related to scaling-up and bringing the technology towards full commercialization. Overall objective is to speed-up the time-to-market, demonstration projects have the following goals:

- production of new information on technology characteristics in a simulated or real-world setting;
- exemplification of a technology to potential adopters;
- encouragement of institutional and organizational changes to facilitate adoption; and
- creation of high-level public policy goals.

Karlström & Sandén (2004) proposed a set of criteria to both select between pilot- and demonstration plants ex ante as well as to evaluate their success ex post. First, although technological success is the ultimate goal, disappointing results or failure must always be taken into account. Therefore, technical experiments generally prefer low visibility. In contrast, exemplary demonstrations prefer clear visibility as their public support is essential for technology adoption and large-scale diffusion. Secondly, whereas experiments require well-controlled and cautious evaluation, examples focus on demonstrating the most realistic setting possible and are primarily evaluated by potential adopters. Thirdly, experimental demonstrations are conducted in a smaller environment that replicate the actual operating conditions to the extent required to validate technical feasibility. Exemplary demonstrations, in contrast, are carried out in a fully operational scale and -environment. Finally, the skeptical attitude of management towards technical demonstrations is different compared to optimistic assurance in commercial demonstrations.

However, the role of demonstration projects may change as a technology progresses through the innovation-development process (Kemp et al., 1998; Macey & Brown, 1990). Demonstration projects ideally must therefore be flexible so they can alter and iterate between fulfilling technical- and commercial roles (Lefevre, 1984). This multi-phased approach maximizes utility and flexibility of the technology demonstration projects. In contrast to the separation of technical- and commercial purposes, a vital third purpose falling in between that is aimed at demonstrating cost reductions in order to make the product and process competitive (Bossink, 2015). Based on empirical work they argue that technology demonstration project indeed have multiple purposes and therefore shift between technical, economic, and commercial objectives (Brown, 2009; Harborne, 2009). Macey & Brown (1990) argue that technology demonstration projects can be categorized in three categories.

First, technological pilot- and demonstration projects for the development of a technical product or process. The collection and transfer of knowledge and experience is crucial, as is the development of strategic alliances within the networks, thereby providing knowledge for regulation. Assessment of the technical feasibility of the innovations. Second, organizational pilot- and demonstration projects aim to physically set-up an organization or consortium that can deliver the product or service. Signaling the possible side-effects of the innovation in an early stage. Concrete formulation and visualization of government policy. Third, commercial pilot- and demonstration projects aim to bring the product or process to the early markets in order to examine the acceptance by different early adopters, examining the financial feasibility, market development through the enlargement of the scale of the demonstration projects.

3.2.3. Key Analytical Dimensions

As literature has indeed recognized the different roles of pilot- and demonstration projects, Hendry et al. (2010) and Hellsmark et al. (2016) delineated five key analytical dimensions:

Risk Reduction – Technical risk refers to technological design choices, the availability of complementary products, and the process of up-scaling. Market-related risk is concerned with the availability of sufficient market demand and the uncertainty inherent to launching a new innovative solution. Organizational risk refers to acquiring future value chains, the participating actors and their roles. Institutional risk is associated with legal rules, beliefs and standards to support the emerging innovation system.

Learning Processes – Technology development is characterized by different learning processes that are necessary to mitigate risk and reduce uncertainties. It involves creating tacit knowledge on technical challenges but is also related to market preferences, institutional barriers and physical infrastructure alignment.

Actors and Institutions – Demonstration activities are generally embedded within actor networks consisting of individual firms, researchers, and other private and public actors (Karlström & Sandén, 2004). These actors shape the context for technological development and could could evolve into advocacy coalitions, thereby increasing consumer awareness and opening-up markets.

Network Performance and Management – The characteristics and performance of the actor network influences how system challenges are dealt with and how networks are reconfigured. Since cooperation and learning processes do not emerge unanticipated, network management becomes essential.

Institutional Pre-conditions – The efforts to manage the various development processes exist within an institutional context of rules, standards and codes of conduct. New technological innovation systems develop in less developed institutional and organizational settings compared to incumbent innovation systems.

3.2.4. Types of Pilot- and Demonstration Projects

Following the key analytical dimensions, Hendry et al. (2010) differentiates between four major types of pilot- and demonstration projects. In addition, Hellsmark et al. (2016) provides a framework for analyzing these roles in progressing technology development. It should be noted that demonstration projects are not mutually exclusive and one project is not a prerequisite for another. Pilot- and demonstration projects may exist in parallel as multiple pilot- and demonstration projects are necessary when industry and potential adopters are highly fragmentated (Brown et al., 1993).

Type I: High Profile Demonstrations and Competitions: High-profile demonstrations projects have clear commercial objectives and seek to gain maximum exposure at minimum costs by raising public awareness and create legitimacy for a specific new product or process in the early development stages. As a result, they do typically not reduce technical risks but may identify market- and institutional risks and constraints. They often precede other types of demonstration projects and are the least complex. High-profile demonstrations are often funded and realized by individual actors or alliances that want to raise public awareness and create legitimacy and receive feedback from potential adopters. Learning is often highly contextual and cannot be transferred. Infrastructure and demonstration results are generally owned, governed, and controlled by individual actors operating in a limited network management structure. They are funded through R&D and marketing budgets of large firms and do not require any alteration of existing institutions at firm- or societal levels. Sponsored competitions can also be used show-and-tell strategy for demonstrations.

Type II: Verification Pilot- and Demonstration Projects: Technology verification projects are more closely allied to research and development and are concerned with testing, evaluating and characterizing different available and working technological solutions. As such, Hellsmark et al. (2016) differentiate between Lab-scale and Industrial-scale Verification Projects.

On the one hand, Lab-scale Verification Projects predominantly operate in the TRL 3-4 range and focus on reducing technical risks for potential stakeholders by conducting a first series of small-scale laboratory tests. The activities facilitate iterations between generating common knowledge and early efforts for up-scaling that can later be applied and tested in a large-scale environment. Another particularly important element thereby is to eliminate the less feasible technical alternatives and consequently progress towards a narrower technology portfolio. In terms of network management, Hellsmark (2010) argues that these first-generation technology verification projects are generally owned and operated by individual organizations and hence have rather uncomplicated actor networks. Nevertheless, individual interests play a crucial role in this phase where learning processes focus on advancing scientific- and engineering knowledge through learning-by-searching (Kamp, Smits, & Andriesse, 2004). As a result, knowledge diffusion from these activities takes place through scientific publications, patents or license agreements. There are limited institutional constraints for building and managing small-scale verification project and funding goes through internal research and development budgets or existing governmental research programs.

Figure 6 - Lab-scale Verification Project

Figure 7 - Industrial-scale Verification Project

On the other hand, industrial-scale verification projects typically operate in the TRL 5-6 range and primarily focus verifying new technologies on a large - but not necessarily commercial - scale. Learning processes are mix of common- and proprietary knowledge development to inform policy makers, society at large and potential adopters about technological opportunities. Therefore, besides reducing technical risks, the main focus is on mitigating market- and organizational risks and to create industrial capacity among technology suppliers and potential adopters. Another major difference with lab-scale verification is that industrial-scale verification actively needs to secure new participants and resources to prepare for subsequent deployment demonstration projects. For that reason, participants try to form industrial alliances and political networks through collaborative development and provide small product values to create niche markets. As large-scale verification requires more funding than often private budget permits and therefore, as often backed by public funding programs, technology development must be aligned with . The combination of public funding and commercial interests, however, appears difficult to manage and hence have potentially complex ownership and network management structures.

Type III: Deployment Pilot- and Demonstration Projects

The third type of pilot- and demonstrations plants are more closely associated with market deployment and field trials and come in two subcategories, deployment- and auxiliary pilot- and demonstration projects. On the one hand, Technological Deployment Projects typically operate in the TRL 7-8 range, see Figure 8, and primarily focused on learning-by-using processes related to advancing operations and thereby improving performance while simultaneously reducing operational costs (Kamp, Smits, & Andriesse, 2004). The complex actor networks are subject to more conflicts of interest when learning-by-interacting processes aim to establish regulations and standards, creating extra institutional risks.

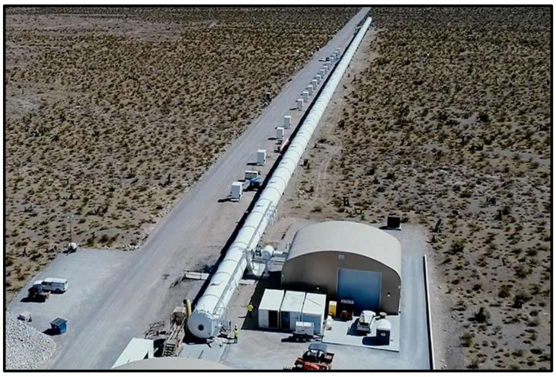


Figure 8 –Deployment Project

Figure 9 – Technological Auxiliary Project

On the other hand, Technological Auxiliary Projects typically operate around TRL 9, see Figure 9, and are primarily oriented towards the market introduction and of down- and upstream auxiliary technologies. Many technological fields consist of a nested hierarchy of auxiliary technologies located up- and downstream of the core technology. The project typically involves broader collaborative actor networks with individual actors having clear roles in the creating the value chain. Learning outcomes center on developing standards and regulations throughout these networks in order to reduce product and organizational risks.

Type IV: Permanent Testing- and Demonstration Projects

The fourth type of pilot- and demonstration projects are permanent testing- and facilities that are concerned with making continuous technological improvements and testing new different technological options. In doing so, they facilitate both basic- and applied research for a wider set of applications. Although permanent test centers lack visibility compared to the other pilot- and demonstration projects, they are able to provide cost-effective technology demonstration activities throughout the entire innovation system development process. Through active and neutral ownership, the management of intellectual property rights is crucial for successful learning processes.

3.3. Dynamics of Technological Innovation Systems

The literature on Technological Innovation Systems (TIS), an approach part of the wider theoretical school on Innovation Systems (IS), emphasizes that technology develops within the context of a system which consists of actors, institutions and technologies. The approach focuses on the structural elements and their build-up processes during the formative stage. The build-up processes have been labeled as the Functions of Innovation Systems and may accelerate as system function interacts, thereby creating a process of cumulative causation. Finally, four generic patterns of cumulative causation, labelled as 'Motors of Innovation', have been identified.

3.3.1. Innovation System Theory

The process through which radical innovations emerge is complex and related to many heterogenous factors. These change processes, however, do not follow a linear path from basic- to applied research, and from early implementation towards large-scale adoption. Scientists and policy makers recognize that technological change is best understood as the outcome of innovation systems (Sagar & Holdren, 2002). Over the last decades, advances in institutional- and evolutionary theories gave rise to the Innovation System (IS) approach. The principal idea behind this approach is that innovation development and diffusion process is both an individual and a collective act (Edquist, 2001). Hence, determinants for technological change are not only to be found within individual organizations, but rather in a broader societal structure in which firms and organizations are embedded and interact (Carlsson & Stankiewicz, 1991; Freeman, 1987; Lundvall, 1988).

The Innovation System approach is a heuristic attempt to conceptualize all societal structures, actors, and institutions contributing to technological change and technological transitions. The approach emerged from seminal work by Freeman (1987), Lundvall (1992), and Nelson (1993) and has become an established framework for innovation policy making. Despite different scholars consider various definitions, different studies share some common grounds. First, all approaches share the emphasis on innovation as a co-evolutionary process. Second, learning processes are considered at the heart of the system building process (Lundvall, 1992). Learning processes, particularly learning-by-searching, depend on the involvement of various actors and organizations, including corporate businesses, governments and research institutes. A third feature is the role of institutions, which can be regarded as the social rules, regulations and routines that shape the behavior of different actors (Edquist & Johnson, 1997). The third feature is the systemic character that stresses the relation between actors and institutions.

The literature presents different conceptualizations that have a specific unit of analysis and has different system boundaries (Edquist, 2001). The oldest conceptualization is the National Innovation Systems (NIS) approach (Lundvall, 1992) and places major emphasis on assessing the innovative performance of a nation state, identifying factors influencing innovative capabilities, and explaining why some are more successful than others (Edquist, 1997; Freeman, 1987). Although such a macro perspective is a heuristic tool for policy analysis, it is rather limited as a research framework as the size and complexity of the actors, institutions and their interactions take dramatic proportions. Alternatively, scholars have applied the Reginal Innovation Systems (RIS) conceptualization to study the innovative capacity and performance of geographical regions (Cooke, Gomez Uranga, & Etxebarria, 1997). A major contribution with respect to the NIS approach is the consideration that geographical distance between actors does indeed affect innovative performance. Although the RIS approach tends to be more micro-oriented towards firm-level structures compared to the NIS approach, it still does not incorporate a detailed analysis of the build-up processes that assemble the system structures. The Sectoral Innovation System (SIS) approach contains a more holistic approach and abandons the limitations of geographical boundaries. Instead it focuses on the level of the industrial sector in which it considers a group of firms developing and utilizing a technology within a specific sector (Breschi & Malerba, 1997). As a result, system structures are shaped by institutional rules that are embedded in the technology, knowledge structure and routines that characterize the innovative activities such an industrial sectors.

3.3.2. Technological Innovation Systems

In recent years, the various "Systems of Innovation" approaches have emerged on the research agenda of different innovation studies (Jacobsson & Johnson, 2000). Nevertheless, the use of the different frameworks for understanding technological change has two shortcomings. First, focus is primarily on comparing the structural elements of the different systems. According to Hekkert et al. (2007), system analyses are often too static and lack sufficient attention to micro-level processes. A more dynamic system approach is needed to grasp a better understanding of what really takes place inside the system during the formative stage prior to system take-off. Secondly, the modern-day globalized economy poses the question whether geographical boundaries are still pertinent and whether firms within systems can be considered to be national at all.

The latest addition to the system framework is Technological Innovation System (TIS) approach. The central idea behind this approach is to a lesser extent concerned with geographical or industrial boundaries, but instead enables a solid examination of the dynamic characteristics associated with a specific emerging technology or technological field, a study of its strengths and weaknesses, and a thorough comparison of the emerging technological system with the incumbent system (Jacobsson & Johnson, 2000). In this context, the TIS approach is a more micro-oriented version of the SIS conceptualization, see. As such, Carlsson & Stankiewicz (1991) defined it as:

> ‘ a dynamic network of agents interacting in a specific economic or industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology.’ – Carlsson & Stankiewicz (1991)

The TIS approach is characterized by the same general features of the other system approaches. However, there a two features through which the TIS approach sets itself apart. First, it emphasizes the ability to develop new business opportunities through knowledge exploitation and recombination as a crucial aspect of technological innovation. Secondly, its major purpose is to analyze and evaluate the system development process in terms of the structures and processes that support or hamper it. In addition to examining the structural configurations, it therefore has a stronger focus towards system dynamics. Moreover, the TIS approach is effective when the subject of analysis is the competition between various technologies that perform a common function, which in our case concerns high-speed transportation.

They examine under what conditions foster the growth of an emerging innovation system, or the technological niche as put forward by (Geels, 2002), so that it becomes so large and embedded in society, that it is able to compete with and even become part of incumbent systems. Therefore, in order to understand technological change insights with respect to the incumbent technology and its innovation system relative to the emerging technology and innovation system is desired. The rate and direction of technological change is not a matter of different technologies simply competing for market dominance, but rather a competition between both developed and emerging innovation systems.

As technological change is the resultant of many interrelated activities, it is necessary to map the relevant activities that influence the wider performance of the innovation system, that is, the functions of innovation systems. Therefore, they present a framework to study technological change on a more dynamic level by mapping functions over innovation systems over time. A dynamic approach would create more insights in the interaction of physical artifacts, organizations, and legislative institutions. Whereas most traditional research in innovation system analysis examines of innovations systems, Hekkert et al. (2007) instead focus on the processes inside the system that boost its performance. The functionality of a technology involves linkages between heterogeneous elements. According to Hughes (1986), technologies, organizations, natural resources, and physical- and legislative artefacts are combined into a ‘seamless web’ in order to fulfill functionalities. The focal point of the approach is the emphasis of interdependencies between system elements and the co-evolutionary processes in which they evolve.

3.3.3. Structures of Technological Innovation Systems

The structural factors, or system components, represent the static aspect of the TIS and are relatively stable over time (Bergek et al., 2008). This does not imply that they are not subject to change. In the formative stage, structures of the TIS are expected to change. However, their rate of change is slow and mainly visible from a long-term historical point-of-view.

Actors and Organizations - The actor category consists of all agents, that is, each individual and any organization, that by providing knowledge and specific competencies are contributing to the emergence of the IS. It is through their specific interests, decisions and actions that new systems emerge and take-off (Jacobsson & Johnson, 2000). Hence, successful build-up depends on the presence, skills and willingness of these actors to take action. As the potential variety of relevant actors is enormous I will adopt the enactor-selector perspective as introduced by Garud & Ahlstrom (1997) to address the reasoning of different actors. Enactors generally consists of small technology developers and industries that are closely involved in the innovation-development processes and are heavily depending on successful outcomes. Alternatively, selectors are engaged from a distance and have the possibility to choose between different technological options. They often involve large firms, financing agencies, regulators and technology adopters.

Formal and Informal Institutions - The institutional structures are at the center of the innovation system. Edquist (1997) considers institutions to be “formal institutions within explicit purpose”, generally understood as organizations. Lundvall (1992) considers institutions as “things that pattern behavior”. Following this second understanding, Scott (1995) distinguished three pillars of institutions. First, the regulative pillar consists of formal codified laws and regulations that are enforced by legal authorities, such as government laws, policy decisions or firm directives. Secondly, the normative pillar constitutes informal tacit rules, such as social norms and values, that are shaped by the interaction and socialization processes between different agents. Third, the cultural-cognitive pillar is often highlighted as the nature of reality, or the collective mind frames through which meaning or sense is made, such as strategic visions and collective expectations. It is important to understand that institutional configurations are generally underdeveloped within emerging systems.

Technological Artefacts and Infrastructures - Technological elements within the system consist of technological artefacts and infrastructures. The techno-economic benefits of these elements, such as cost structures, safety measures, reliability characteristics and up-scaling effects are crucial to understanding the progress of technological change (Markard & Truffer, 2008). Moreover, more intangible aspects, such as tacit knowledge and characteristics of the value chain are equally important. Although the importance of technological structures has been largely neglected, technological features enforces rules through which the actions of different actors are constrained.

4) Relationships and Networks - The three structural factors mainly serve as building blocks and need to be intricately linked together for a system to successfully emerge. The relationship between actors is characterized by mutual autonomy and the provides guidance for action, such as collaborations and competition. By contrast, the relationships between technologies and institutions contain guidance for design as system rules could contradict or reinforce each other (Murmann & Frenken, 2006). The linkages within a particular structural group will be more robust than linkages outside these groups. Once the structural elements constitute a solid configuration, they are conceived as industrial network structures. Networks are essential during system build-up processes as they facilitate interactive learning processes between actors. Moreover, they are of prime importance to the dynamic processes within the innovation systems as they are the result of both structural tensions and synergies that are created by the various relationships that are formed.

3.3.4. Functions of Innovation Systems

The structural factors have so far been described as the static elements that make up the system at any given moment in time. Nevertheless, the structural analysis has some serious drawbacks when insights in the dynamic build-up processes are explored. Especially within the formative stage, actors and institutions should be considered as endogenous variables that often change as progress unfolds (Carlsson et al., 2002). More recently, the underlying key processes to describe and explain the build-up processes within the formative stage of innovation system development have been studied. The Functions of Innovation Systems (FIS) approach is based, amongst others, on work by Jacobsson & Bergek (2004) and Hekkert et al. (2007) and considers system functions as the dynamic elements of the innovation system that develop over time. The following seven system functions have been identified:

F1: Entrepreneurial Activity - The presence of entrepreneurial activity is at the core of well-performing IS. Although the concept of the "entrepreneur" is generally related to a single private actor, from a system perspective, the entrepreneur can also be a public institution or a combination of public and private actors. It is the responsibility of the entrepreneur to turn new knowledge, networks and potential markets into activities that generate new business opportunities. Entrepreneurial activity is necessary to abate the fundamental uncertainties associated with emerging technologies (Carlson 1991). Nevertheless, through emerging technologies may gradually shape to fit its intended environment. In doing this, entrepreneurs are likely to overthrow and change parts of the structures around him, thereby forcing technological change into new directions. The entrepreneur can be either new business entrants that have a clear vision towards the future, or incumbent companies who aim to diversify their business strategy in order to retain a sustained competitive advantage. The function can be mapped by identifying the number of new business entrants, the number of diversification activities of incumbent actors, and the number of new projects started.

F2: Knowledge Development - The Knowledge Development function involves various learning processes that are central to emerging technologies, markets and networks. Therefore, R&D and new knowledge development, encompassing learning-by-searching, learning-by-doing, learning-by-interacting, are prerequisites within the formative stage. Learning-by-searching activities involves R&D activities in basic- and applied science, whereas learning-by-doing concerns learning activities in a more practical context, such as small-scale laboratory experiments and adoption trials. The Knowledge Development function is generally accomplished by universities or other scientific research institutes. Additionally, contributions by the entrepreneur are also reasonable when learning-by-doing is considered. The function can be measured by identifying the number of projects, the number of patents applied and granted, and amount invested in R&D. A more holistic approach, however, is to include the performance output in terms of learning curves.

F3: Knowledge Diffusion through Networks - The organizational structure of Innovation Systems is created though networks. According to Carlsson & Stankiewicz (1991), the primary function of network activities is to facilitate the exchange of information. This is crucial within individual R&D departments but especially in a heterogenous context where innovating organizations meet government agencies, competitors and early market participants. In other words, for an Innovation System to flourish, it is imperative that knowledge is interchanged among variety of actors with different backgrounds that interact through networks, that is learning-by-interacting. A special form of interactive learning is learning-by-using, which involves learning activities based on user experiences through user-producer networks (Lundvall, 1988). Moreover, knowledge networks allow policy decisions, such as standards and long-term targets, to be based on the latest technological information. Knowledge diffusion activities involve formal partnerships between different actor groups as well as workshops and conference meetings. Hence, the knowledge diffusion function can be measured by identifying the network size and intensity over time.

F4: Guidance of the Search – The various processes shape the needs and requirements of actors and provide guidance with respect to their support. These can be individual decisions regarding technological options or wider institutions such has policy targets. In addition, promises and collective expectation are based on the state of the emerging technology and its fit to the incumbent system (Markham et al., 2010; H. van Lente et al., 2013). Therefore, they serve as important determinants for degree of technological legitimacy, which in turn could attract new actors and stimulates the allocation of sufficient resources. A positive contribution implies an aggregation, converge and momentum of positive signals to a certain direction of technological change, whereas negative contributions, by contrast, could lead to rejection of the technology altogether. In an evolutionary context, where knowledge development represents the creation of technological variety, Guidance of the Search is regarded as a selection mechanism that translate broad visions into a concrete directions (Nelson & Winter, 1982). The Guidance of the Search function can be measured by identifying specific ambitious policy targets set by public institutions and industries and by mapping the number of promises and expectations about the emerging technology.

F5: Market Formation – Prevailing lock-in effects uphold barriers that emerging technologies encounter while competing with incumbent technologies and markets (Rosenberg, 1976). Especially during the early phases of development, these technologies are relatively inefficient, offer marginal advantages and are inadequately aligned to the characteristics of the incumbent system. Therefore, they cannot immediately compete successfully and diffusion under these circumstances will be slow or even fail. As a result, Market Formation involves the activities and decisions that contribute to the initial demand creation. A first approach to cope with this is to create a temporary protected niche environment in which learning process are further stimulated and expectations can be developed (Smith & Raven, 2012). A second possibility is to create a competitive advantage by initiating tax exemptions or minimum consumption quota on the demand side. The rationale behind supporting emerging technologies through market supportive policies has been the subject of analysis in the Strategic Niche Management (Kemp et al., 1998; Schot et al., 1994; Smith & Raven, 2012).

F6: Resource Mobilization – Financial, material and human capital are fundamental ingredients for innovation. Emerging technologies cannot be supported if financial budgets or actors with appropriate skills and competences are missing (Carlsson & Stankiewicz, 1991). Since access to sufficient resources is necessary to facilitate the production of new knowledge, Resource Mobilization is considered to be a major input for the knowledge development function. It is therefore considered a major underlying factor determining the success or failure of a project (Negro, 2007). Typical activities are the allocation of subsidies and investments for long-term research and development programs set up by industry and government or funds made available to support pilot- and demonstration projects. Although the resources may be provided by different kind of actors, more actors contribute as technology maturity progresses. In spite of this, the resource mobilization function is difficult to map as specific performance indicators are missing. The best suited method is to observe whether actors perceive access to sufficient resources as problematic.

F7: Creation of Legitimacy and Counteract Resistance to Change – An emerging technology has to become part of an incumbent socio-technical regime or even has to overthrow it (Geels, 2002). However, organizations with vested interests in the incumbent regime will often counteract this force of "Creative Destruction" (Schumpeter, 1942). As a result, lobby or advocacy coalitions may serve as a catalyst by putting the technology on the agenda and consequently lobby for resources and favorable tax regimes. With that they create and enhance technology legitimacy and strengthen its technological trajectory. Successful coalitions will grow in size and dominance and may become powerful enough to empower a regime shift. The Creation of Legitimacy function can be measured by identifying the rise and growth of various interest groups and mapping their lobby activities.

3.3.5. Motors of Sustainable Innovation

An important implication from the FIS approach is that system innovation has no single cause. The build-up process accelerates when system functions link-up simultaneously and reinforce each other over time. Therefore, the system functions should be understood as a set of activities that are at the core of the system build-up process. Since this process does not come into practice overnight, understanding the way in which system functions interact and develop over time is crucial. The system functions influence each other and fulfillment of certain system functions is likely to trigger the other system functions. These interdependencies could induce positive feedback loops, thereby creating a dynamic environment of cumulative causation. Consequently, acceleration in system innovation occurs when system functions interact and create virtuous cycles. Additionally, virtuous cycles are positive feedback loops that strengthen each other. An example of a virtuous cycle is provided by Suurs (2009): successful fulfillment of a project results in higher expectations, thereby contributing to the Guidance of the Search (F4) function. Subsequently, this may trigger the allocation of subsidy streams, thereby fostering Resource Mobilization (F6). In turn, this facilitates even more research activities that contribute to the Knowledge Development (F2) and Guidance of the Search (F4). This momentum is necessary for an IS to take-off.

The structural elements of the IS and its functions are mutually dependent. The system structure influences the system functions and vice versa (Markard & Truffer, 2008). It is evident that such interaction between system functions result in positive feedback loops which in turn are considered necessary in building-up the

TIS. Although virtuous cycles result in a build-up of system structures over time, positive feedback mechanisms suggest that a reinforcement of causes is not limited to system build-up processes. System functions may, paradoxically, induce conflicting development, reinforce each other downwards, leading to reduced or counteracted activities that cause standstill or even a partial breakdown of the IS structures. In contrast , vicious cycles occur when negative function fulfilment result in reduced activities in related function, thereby slowing down or even halting the process of technology development (Hekkert & Negro, 2009).

In other words, the existing structural elements from which these cycles emerge are affected by its own dynamic character. In respect of the build-up phase of a Technological Innovation System, this implies that with each turn of the cycle, structural configurations also shift to reinforce the activities within the cycle. Virtuous and vicious cycles thus emerge from a present configuration of structural elements while simultaneously rearrange that structural configuration. The motors of sustainable innovation are independent of the structural configuration of the innovation system. On the contrary, the motors emerge from structural configurations and in turn reconfigure the structural elements. Various scholars have applied the FIS approach to study the interaction between different system functions over time. Through longitudinal case studies in the renewable energy industry, several virtuous and vicious cycles were identified that support their explanation of successes and failures in emerging IS in achieving breakthrough success. In particular, four conceptualizations of virtuous cycles, labeled the “Motors of Innovation” are conceptualized by Suurs (2009):

Science and Technology Push Motor: The event sequence that characterizes the Science and Technology Push (STP) Motor starts with positive expectations or research outcomes [F4] resulting in governments setting-up R&D programs [F4] and granting financial resources [F6]. These programs, then, boost scientific activities, such as feasibility studies and small-scale laboratory trials [F2], and knowledge diffusion through conferences, workshops and meetings [F3]. In the next cycle, or parallel, the government approaches other firms and research institutes to participate in projects targeted at the realization of pilot- and demonstration plants [F1]. The willingness of those organizations to participate in these risky ventures very much depends on the outcomes of the feasiblity studies [F4]. Positive outcomes could attract firms to invest, thereby contributing to the expansion of the research program [F4, F6]. Negative outcomes, by contrast, may have the opposite effect [-F4, -F6], although research programs may continue once resources are in place.

Entrepreneurial Motor – The dynamic pattern of the Entrepreneurial Motor involves an event sequence starting with firms, utilities or local governments entering the system and initiating innovative projects [F1]. This usually involves small-scale demonstration projects as they see opportunities for commercial or societal benefits [F4]. In some cases the dynamics are reinforced by the existence of niche market activities [F5]. In the second cycle, given the immature technological character, actors lobby the national government for financial resources to cover the costs and compensate the risks [F7]. If successful, subsidies are granted [F6] and the projects are started [F1]. The result feeds back into the dynamic and provides stronger incentives for other actors to participate or refrain from doing so [F4]. An important difference compared to the STP motor is that, in a third cycle, knowledge development [F2] and knowledge diffusion [F3] strongly interact with entrepreneurial activities [F1] since the feasiblity studies and laboratory trials are now complemented by learning-by-doing activities that take place in the technology demonstration projects.

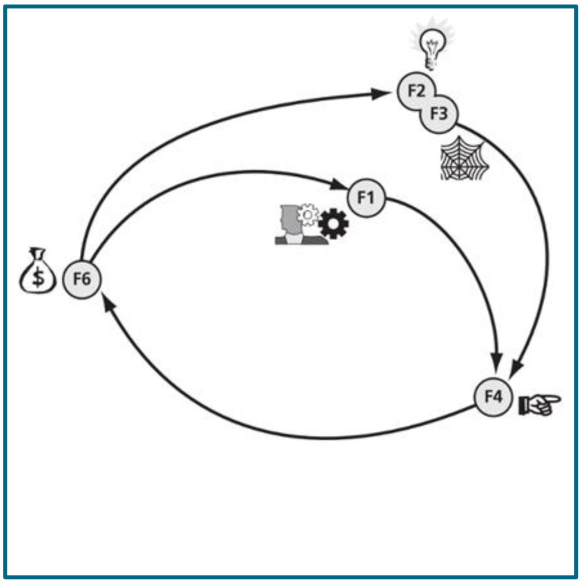


Figure 10 - STP Motor

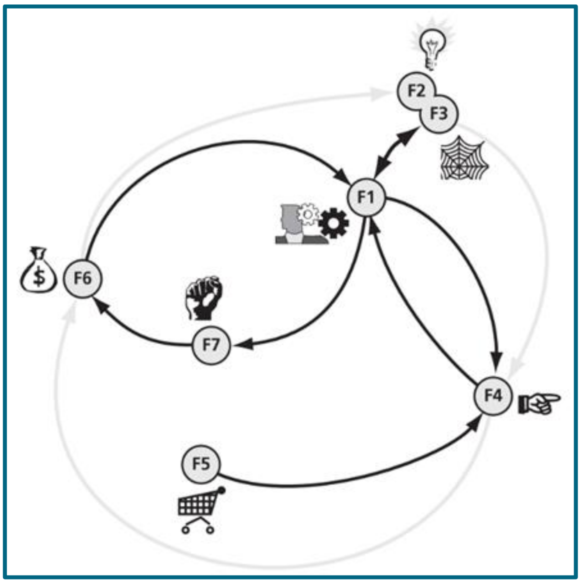
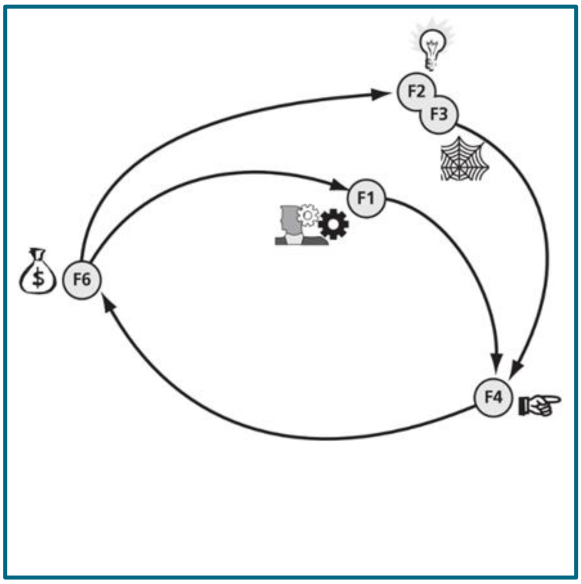


Figure 11 - Entrepreneurial Motor

System Building Motor – The dynamic pattern of the System Building Motor involves an event sequence starting with firms joining innovative projects and organizing themselves in knowledge sharing platforms to coordinate further technological development [F1, F2, F3]. Within these platforms, they also lobby the national government for generic policy support to mobilize resources and develop institutions [F6, F7]. Whereas in the Entrepreneurial Motor lobbies are generally aimed at securing project-specific subsidies, lobbies in the System Building Motor are typically directed towards achieve policy measures that facilitate expansion of the innovation system as such. Additionally, the aim of the organized platforms is the creation of a mass market [F4, F5].



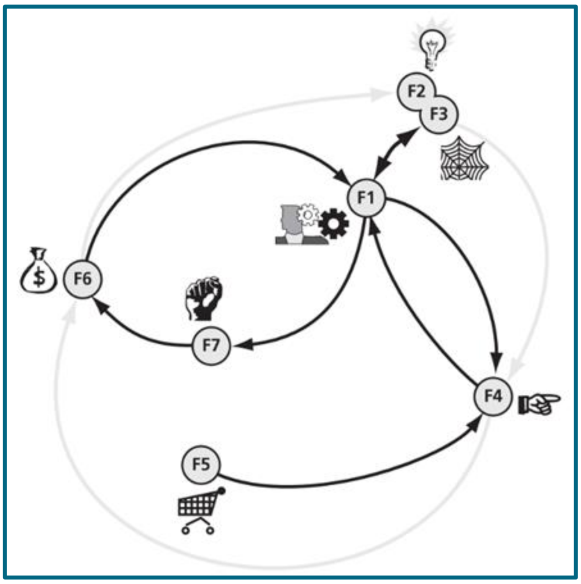


Figure 12 – System Building Motor

Figure 13 - Market Motor

Market Motor – The Market Motor involves an event sequence starting with the creation of institutional structures that directly facilitate a commercial market for the emerging technology [F5]. These structural elements result in an increase in expectations and the allocation of resources. [F4, F6]. Consequently, this leads to the possibility for new entrants to adopt the emerging technology and to large infrastructure investments [F1, F6]. Furthermore, these entrants may also develop marketing strategies in order to increase market demand even further [F5].

3.3.6. Succession Model of Innovation

The build-up processes of an innovation system accelerate due as system function interact and reinforce each other over time. The four motors of innovation have been related to structural drivers and barriers and to their structural impact and are integrated into overarching perspective on build-up processes of an innovation system. based on the idea that the motors are related to each other in the sense that they are likely to build up one another. The idea of a progressive sequence of motors of innovation unfolding according to a fixed pattern is a tough observation in line with the linear model of innovation. Nevertheless, the stages development is not a linear development. The processes and mechanisms underlying each motor involve a variety of system functions that interact by means of multiple feedback loops. The motors are considered as consecutive sub(stages) within the formative stage. The individual motors are characterized by specific drivers and barriers. Once the drivers are supported and the drivers are reduced, a shift towards a more advanced motor may be the result.

Figure 14 - Succession Model of Innovation

3.4.Technological Transitions

The notion of Technological Transitions (TT) has become widely accepted by scholars linking the social, economic- and technical dimensions of technological change (Geels, 2002). These transitions are defined as major transformations in the way important societal functions are fulfilled. The transformation processes are not limited to technological changes, but also involve transformations in the user practices, infrastructures, industrial networks and policies. The processes consist of multiple causalities and co-evolutions that are caused by independent developments.

Successful TTs are not solely the result of technological success but also by the wider innovation system that develops. The dynamics of IS considers technological transitions as important determinants for the direction and rate of innovation and technological change. The emergence of new IS and changes in incumbent ones co-evolve with technological change. Although technologies and artefacts play important roles in fulfilling these functions, the technology on itself has no power on its own and does nothing. It is only in interaction with social structures and organizations that technologies and artefacts are able to fulfil certain societal functions. The heterogeneous elements within the socio-technical system are actively created and maintained by human actors, which in turn are embedded in social groups. The approach is highly multidisciplinary and includes insights from disciplines ranging as far as evolutionary economics, innovation studies, sociology of technology and complex system theory. Nevertheless, LTS research has focused particularly on the emergence of new LTS, rather than on the change from one system to another.

Therefore, understanding technical change involves obtaining insights in the relation between incumbent technology and the incumbent innovation system with respect to the emerging technology and its emerging innovation system. The MLP of system innovations emerged at the crossroad of evolutionary economics and science- and technology studies and describes long-term technological transitions as change processes of bringing one socio-technical system towards another. Technological transitions are analyzed through the MLP that considers three analytical levels: exogenous landscape developments, socio-technical regimes and technological niches. The central idea is that TT are patterns unfolding from three system levels that are driven by the interplay of dynamics arising from each level. The breakthrough and diffusion of radical innovations depends on the link-up with ongoing processes at the regime and landscape levels that create a technological window of opportunity (Geerlings, 2012).

Technological transitions are the result of complicated processes that have developed over long periods of time and have spread over large geographical regions. In order to comprehend these macroscopic processes, understanding the underlying core processes is essential. Following an observation of historical transitions by Grübler, Nakićenović & Victor (1999) technological innovations are considered to as being such core processes as transitions emerge around groundbreaking technologies. The emergence of radically new technologies is far from a coherent process and often goes along with high levels of uncertainty to all stakeholders involved. Although incremental innovation is dominant form of innovation and generally concerns enhanced performance on existing products, processes and services, it is non-incremental or radical innovation that in the past has serious market impact, thereby changing market structures, render existing markets obsolete or even establish new state-of-the-art markets that address great societal concerns (Freeman & Soete, 1997).

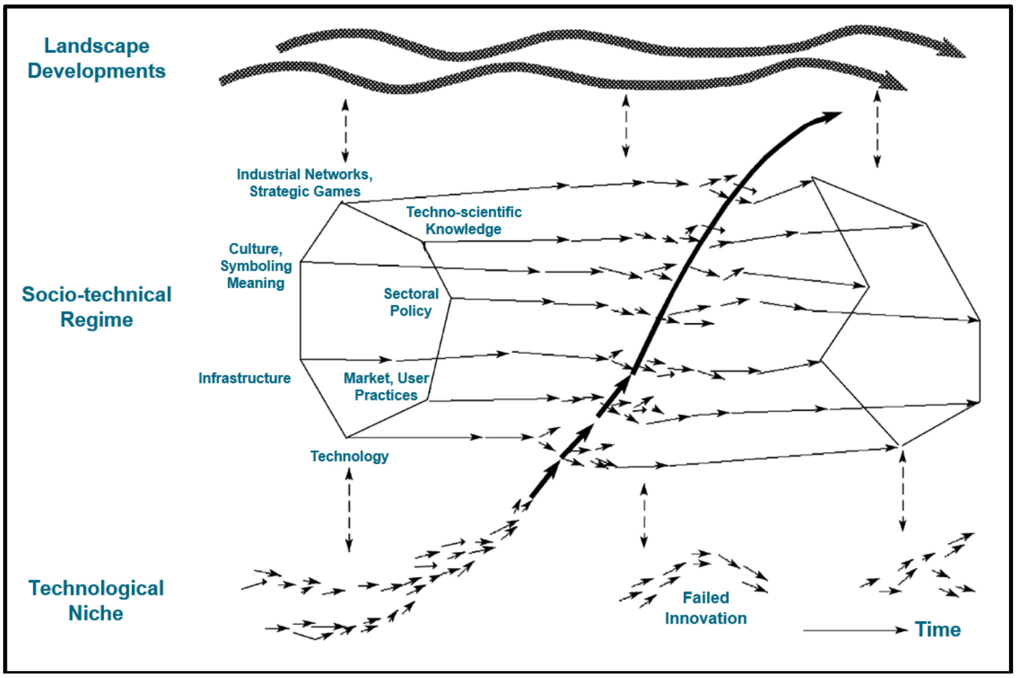


Figure 15 - A Multi-level Perspective on Technological Transitions

These non-incremental technological developments are complex, discrete and discontinuous events involving new connections, thereby only having minor relations to incumbent technologies (Dahlin & Behrens, 2005). Additionally, so-called "large-scale" innovations, or "megaprojects" in project management literature (Flyvbjerg, 2014), are characterized by long lead times, large infrastructure investments and the involvement of many public- and private stakeholders, such as mobility projects or renewable energy projects. These complex ventures take many years to develop and could potentially impact millions of people.

The multi-level perspective is developed to understand these large regime shifts. By combining relevant insights from evolutionary economics and the sociology of technology studies, it analyzes the interactions between technological niche developments and incumbent socio-technical regimes, both situated in a wider landscape environment (Geels, 2005). The literature considers transitions as historical patterns unfolding driven by the interplay in three system levels: the landscape developments (macro-level), the socio-technical regime (meso-level), and the technological niche (micro-level).

3.4.1. Landscape Developments

The macro-level of the multi-level perspective consist of landscape developments. The technological trajectories are located in a socio-technical landscapes. The processes in the external environment consist of deep structural trends that are exogeneous to the socio-technical regime. Landscape developments are beyond the direct influence of individual actors and social groups and hence cannot be changed at will (Geels, 2004). Hence, it is evident that these landscape developments are even more difficult to change than changes of the socio-technical regime. The trends within the landscape level are heterogeneous and may include features like economic growth, environmental concerns, broad political coalitions, cultural and normative values, and resource scarcities. Geels (2005) identified two variants of landscape developments. The first type consists of relatively slow developments in line with Braudel's view on 'longue durée'. such as cultural- or demographic changes and shifts in the political ideologies and systems. The second type of landscape developments consist of relatively fast developments, such as wars, changes in oil prices and economic strength.

3.4.2. Socio-technical Regimes

The meso-level of multi-level perspective consist of the socio-technical regime and considered to be the main research object. The concept of "technological regimes" is coined by Nelson & Winter (1982) and refers to the shared cognitive routines that explain the emergence of technical trajectories. Rip & Kemp (1998) included a more sociological character and defined the technological regime as:

> "the rule set (...) embedded in a complex network of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures."

Although technology and technological artefacts are important in fulfilling societal needs, it is only in interaction with human agency, social structures and organizations that they fulfil these functions (Geels, 2005). The stability of the incumbent socio-technical regimes originates in the linkages between a heterogeneous set of elements. Societal functions are fulfilled by socio-technical configurations, skills are part of routines, behavioral patterns and organizations. However, the concept of technological regimes mainly refers to the design and production of a specific technology and is too narrow to analyze and understand the dynamics in the entire socio-technical system. The elements of socio-technical systems and their linkages are the result of activities of a wide range of social groups, such as engineers, suppliers, scientist and policy makers and consumers. Although technological regimes account for the stability of technological development, it does not imply that technological regimes are static. The regimes refer to shared cognitive routines and rules that provide coordination for action and interaction. Hence, rules shared among social groups or communities, activities tend to steer activities in the same direction, resulting in stability and coordination. The activities within a configuration are aligned and coordinated to each other.

3.4.3. Technological Niches

The technological niche represents the represents the micro-level of the multi-level perspective. Whereas incumbent regimes often produce incremental innovations and benefit from economies-of-scale and network externalities, radical innovations are generally potrayed as "hopeful monstrosities" (Mokyr, 1990). From an evolutionary perspective, the socio-technical regime constitutes the selection environment for technological development, thereby exerting a significant barrier for radical innovations to emerge. The path dependent and stable character at the regime level raises difficulties in creating radical innovations. As a result, the principal force of innovation is situated on the niche level. Racially new technologies are cumbersome, have poor initial performance and are rather expensive. As a result, radically new technologies are not able to compete with and survive in normal mainstream markets and therefore need to be protected. Technological novelties emerge in technological- and market niches. These niches are crucial for system innovation as they provide the seeds for change. The technological niches act as incubation rooms for novelties, thereby shielding new technologies from mainstream market selection mechanisms. In doing so, they may prompt the interest of other actors to mobilize resources for further research and development.

Technological niches are important for technological change because they sow the seeds for change. Niche developments emerge in two types, technological- and market niches. The former provides protection in the form of public R&D subsidies or strategic private investments. The latter through creating special application environments. Technological niches are characterized by uncertainty. Design rules are ambiguous and it is unclear. Additionally, technological niches also create a network environment to build social relationships which support the innovations, such as supply chains, user-producer relationships. Different social groups are willing to support and invest in niches as they have certain collective expectations with regard to future benefits. The role of technological niches in the emergence of radically new technologies has been studied and described in the field of Strategic Niche Management (SNM) literature (Kemp et al., 1998; Schot et al., 1994; Smith & Raven, 2012) According to the SNM literature, three processes are crucial for successful development of technological niches.

If the internal processes do reinforce over time the niche may collapse. learning processes and technical perforce do not satisfy the technological expectation, actors may leave the support network. (Geels, 2005) argues that these processes reinforce and stimulate each other, the niche will expand and stabilize. New technologies emerging at the niche level are often projected on problems perceived in incumbent socio-technical regimes. However, as the stability of existing regimes emerges from interlinkages between heterogeneous elements in the socio-technical system, a mismatch between niche and regime could hinder a successful breakthrough. Radical niche innovation often face struggles against entrenched regimes with are stabilized by various technological and economic lock-in mechanisms. Range of elements are intertwined and linked together, such as technology, regulation and policy, markets and user practices, cultural and symbolic meaning, infrastructure and production and maintenance systems. The cluster of interlinked social- and technical elements is called the "socio-technical system".

3.4.4. Patterns and Mechanisms

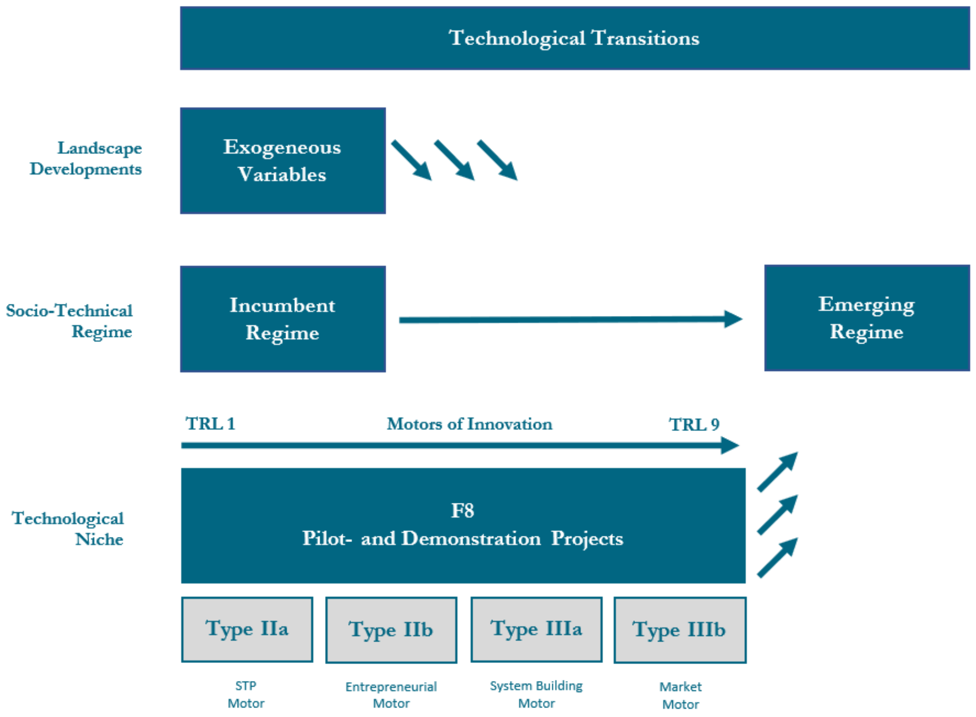
TTs are characterized by long formation periods followed by a rapid take-off (Grübler et al., 1999). The relationship between the three levels of the MLP can be seen as a nested hierarchy. In other words, technological niches are embedded in socio-technical regimes, which in turn are embedded with in landscape developments (Geels, 2002). The essence of the MLP is that TTs and regime shifts occur through dynamic interaction of the three different levels (Geels, 2005). Rather than superficial cause-and-effect relationships, circular causality ensures that processes link-up, reinforce each other and induce regime shifts (Suurs, 2009)The emergence of radical ideas in technological niches is strongly influenced by incumbent regime and landscape developments. The success of new technologies is therefore not solely determined by successful developments within the technological niche level, but also by development at the regime- and landscape level. Changes in the landscape level may put pressure on the socio-technical regime and create openings for new technologies. For example, the global environmental campaign towards a sustainability transition is an exogenous landscape development that puts pressure on the incumbent socio-technical regime.

Therefore, the MLP analysis first identifies the heterogeneous elements of the socio-technical regime, shows how they interact with each another, how changes in one element might trigger other changes, and how ongoing processes and developments gradually link up. Nevertheless, the emergence of technological niches is heavily determined by existing socio-technical regimes and landscape developments. As stated before, novelties emerge in technological- and market niches. Technological niches crucial for technological change as they sow the seeds for future change. Nevertheless, the multi-level perspective only considers processes internal to the niche. Although the interplay between niche and regime is presumed to be imperative for technological change, the actual processes that support and enable such interplay are not specified. As a result, insights into activities in a technological niche to become part or even overthrow the incumbent regime and key processes that support a successful breakthrough from a niche towards a regime are needed. In order to accommodate this, the TIS System approach provides some good starting points.

As a result, the success of a radically new technology is determined by processes on all three levels and only legitimate alignment of developments. The outcome of linkages between the development at multiple levels will determine if a regime shift occurs (Kemp, Rip, & Schot, 2001). Geels (2002) described how technological transitions come about on the basis of evolutionary economic and technology studies. Examines particular patterns and mechanisms in the transition processes. From evolutionary economics, there are two views of technological evolution. One considers evolution as the process of variation, selection and retention. The other view considers evolution as the process of unfolding and creating new combinations. From an evolutionary perspective, radical variety is generated in technological niches whereas the socio-technical regimes serve as selection and retention mechanisms. An important question in the literature on TTs relates to the circumstances under which a technological niche becomes so successful that it becomes part of or even overthrows an incumbent socio-technical regime. In addition to the MLP and SNM, the Innovation System approach goes takes one. Although a broad perspective is needed to comprehend TTs, a solid understanding of the underlying processes required to understand its emergence. Socio-technical regimes are stable because the activities of the social groups are aligned and coordinated. However, the stability on itself has a dynamic character, implying that incremental developments in the activities of social groups occur frequently. Therefore, the socio-technical system remains 'dynamically stable" for as long as the activities and incremental changes are aligned and go in the same direction. It is therefore evident that the degree of alignment is a legitimate indicator of the stability within socio-technical systems. However, tensions between the different social groups and their activities groups result in a weakening of linkages and creates a possible window of opportunity for radical novelties to emerge. Another drawback of the definition by Rip & Kemp (1998) is the bias towards novelty and its innovation journey. The socio-technical system on itself has various ongoing processes, such as the emergence of new markets, dynamics in the political landscape and new technologies.

3.5. Theoretical Framework

Now that the three branches of literature have been discussed, a theoretical framework is constructed to conceptualize the different fields into an overarching perspective. In doing so, a new function F8 Pilot- and Demonstration is proposed as contribution to the Functions of Innovation Systems framework.



System Function	Description	Events
Function 8: Pilot- and Demonstration	Demonstration is crucial throughout the entire innovation process, whether small-scale, industrial scale or full application.	Laboratory Experiments Demonstrations Pilots and Trials

Table 2 – Proposed Function for Technological Innovation Systems

PART C – EMPIRICAL ANALYSIS

4. Method for Case Study

4.1. Introduction

The fourth chapter contains describes the methodology for the identification and measurement of both the system structures and functions. This approach is called the Even History Analysis. Consequently, section two discusses the origins of the approach and section three explains how the data is gathered and processed.

4.2. The Event History Analysis

In order to thoroughly analyze the interactions between system structures and functions, a dynamic analysis that reconstructs the sequence all relevant system processes is necessary. The processes approach or sequence analysis has been primarily used in research oriented towards firm-level innovation trajectories (Poole et al., 2000; Van de Ven, 1993; Van de Ven et al., 1999). The micro-level focus of this approach tracks daily events within a firm, enabling extraction of dynamic patterns on the nature of organizational learning. Nevertheless, research on emerging TIS entails a far more holistic focus than just individual firms. The underlying basis of studying these TIS dynamics can be found in the event history analysis.

The event history analysis is an approach to systematically analyze complex longitudinal data that based on the so-called process approach or sequence analysis developed by Abbot (1995), Van de Ven et al. (1999) and Poole et al. (2000). The event history analysis offers a thorough methodology for operationalizing and measuring system functions by linking them to certain events. The complexity and timeframe in which new these IS to emerge typically make an ex-post analysis more suitable. The data collection is thus not focused on monitoring events of importance to individual actors and system structures, but rather on events are have far-reaching implications on the IS itself, that is, events that contribute in one way or another to the fulfilment of FIS. Moreover, the event history analysis follows from the construction and qualitative analysis of a storyline rather than on the identification of quantitative relations. As stressed by Hekkert et al. (2007), the dominant research strategy in social sciences, the variance approach, is incapable of analyzing how the fulfilment of certain system functions leads to system change. This approach is perfectly suited for explaining continuous technological change driven by unidirectional deterministic causation, yet it ignores the sequence of events. An appropriate method that conceptualizes the development and change processes as a sequence of events is the process approach or sequence analysis. The process approach creates meaningful insights into the underlying mechanisms that foster or hamper technological change over time. In contrast, other approach that often primarily focus on the structural aspect of system innovation. Ultimately, the empirical case study around magnetic levitated transportation technology should result in the identification of system structures and functions that were influential to the TIS formation.

4.3.Reconstructing the Storyline

In the face of its complicated history, the choice for magnetic levitated transportation technologies presents an interesting case for analyzing the build-up processes around system innovations. Although it has been developing for almost sixty years, large-scale adoption and diffusion have remained marginal. The foundation of the event history analysis is the construction of a narrative of the emerging innovation system around magnetic levitation transportation technologies or labelled the Magnetic Levitation Transportation Innovation System (MLTIS) from now on. This storyline consists of the sequence of events that had major implications on the innovation system development. The narrative is established by means of the following procedure.

Data Collection and Database Construction – The starting point for the empirical case study is to perform a desk search and collect data from various literature sources, such as professional journals, newspapers, reports and websites. Valuable instruments are the Nexis Uni and Delpher databases containing plenty of legal, academic, and journalistic documents. The major advantage of digital collections are the use of search queries, enabling a powerful way to sample a collection without having to scan through vast amounts of literature sources. The focus is on aggregate and long-term patterns, not on individual actors and day-to-day interactions. Once the data is collected, a database is constructed containing all relevant events in chronological order. Note that the objective is not to identify all causal relationships within the system but is limited to the events that have a present drivers, barriers and structural impacts on the build-up processes of the IS. The database will be organized according to the MLP. This implies that events are categorized in different levels in order to explain exogeneous landscape developments, describe elements of the incumbent high-speed transportation regime and define niches as the progressed over time.

Structural and Dynamic Analysis – The database provides a systematic overview of the sequence of events and the time of occurrence. In the following step, the events are clustered into system functions and assigned to system structures. The symbols [F1] to [F8] refer to the system functions that were described in the theoretical framework and refer to the organizational, institutional and technological structures. Note that most events have positive designated signed and some have a negative sign. This provides an indication whether the system function positively or negatively contributes to the innovation system development.

Narrative Reconstruction – A storyline is created that narrates how the sequence of events unfolded over time. Now that the events are extracted from the literature and allocated to the system functions, the following step is to study the event data for trend patterns and interaction patterns. Following the historical analysis, the virtuous cycles that constitute the motors of innovation are highlighted. The analysis is validated by checking the results through interviews with various experts in the field. Check for false validity and factual errors in the storyline: Van Pernis (Siemens), Ulrich (Transrapid), Doi (JR Central), Vomhof (Transrapid International), Van Gessel and Welsenis (independent industry expert).

5. A High-Speed Maglev Case Study

5.1. Introduction

The fifth chapter contains the empirical analysis on the role of Pilot- and Demonstration Projects (PDP) in emerging Innovation System (IS) development. The purpose of applying the Functions of Innovation Systems (FIS) approach is to understand and explain de role of PDPs in the build-up processes of a Technological Innovation System (TIS), and subsequently, to understand how technological niches become powerful enough for a Technological Transition (TT) to take place. It analyzes the system functions and structures that were part of the Magnetic Levitation Transportation Innovation System (MLTIS) formation between 1966-2012. It involved technical changes, but also organizational and institutional changes throughout the entire innovation system. The analysis shows how attempts of the technological transitions towards magnetic levitated transportation technologies evolved in the context of rail- and air transportation.

5.2. Case Structure

The analysis shows how the heterogeneous elements interacted, how changes in one element triggered changes in another, and how multiple developments gradually linked up. The multi-level interaction occurs between landscape, regime, and technological niche level characterize the course of action in system innovation. The key objective is analyzing the build-up processes on the niche level that contributed to the emergence of the MLTIS. In this historical analysis the key processes are highlighted. The symbols [F1] to [F7] correspond to the seven system functions from the FIS framework. The analysis is evaluated and validated through interviewing industry experts in the field.

Therefore, the analysis in each episode starts by describing the developments at the landscape level and high-speed transportation regime. Consequently, the activities that were part of the emerging MLTIS are explained in terms of developments in the technological- and market niche developments. It is in this context where radical technologies are developed and new IS emerge. In order understand the TT in the socio-technical rail transportation regime the analysis extents by incorporating a reconstruction of the dynamic interactions between the different levels resulted in the emerge of a new IS. For each episode, the MLP tried to answer the following questions:

- What were the relevant external landscape developments?
- What were the developments in the high-speed transportation regime?
- Which novelties emerged within technological niches?

The various levitated transportation technologies have emerged over the last decades. The case study focuses primarily on high-speed magnetic levitation applications and that Germany and Japan were dominant countries in the early maglev technology development. Despite high expectations throughout the years, recurring technological, economic and societal barriers refrained magnetic levitation from entering the high-speed transportation regime on a large scale. The development of the MLTIS can be classified according to three major episodes. The first episode (1966-1977) is characterized by the rise of the magnetic levitation technology in an environment where high-speed rail and air transportation were creating the socio-technical system around high-speed transportation. The research and development programs were oriented towards lab-scale pilot- and demonstration activities. The second episode (1978-1996) is characterized by the expansion of the high-speed transportation regime and competition between alternatives in the technological niche development; development on electromagnetic levitation in Germany vs. development on electrodynamic suspension in Japan. Although the high-speed transportation regime is expanding, developments at the landscape level put the regime on pressure and create an early window of opportunity. The third episode (1997-2012) is characterized by the early commercialization attempts that were made of both technological options. The pilot- and demonstration activities shifted from technological demonstration towards public demonstration activities However, economic feasibility on maglev remained questionable and high-speed rail was often favored.

5.3. History of High-Speed Transportation

The emergence of rail- and air transportation constitutes the early developments within the wider transformation process towards high-speed transportation. Therefore, it is particularly necessary to describe its emergence in order to understand the context from which magnetic levitation transportation technologies emerged. The following section therefore has less focus on roles of pilot- and demonstration projects and is primarily concerned with setting the stage. It includes a multi-level review of the socio-technical elements and social groups that shaped the early rail- and air transportation industries.

5.3.1. Landscape Developments

The beginning of the 20th century was characterized by economic and societal optimism. There was a common desire for technological progress and people felt they were entering a new age through technological utopianism (Carrico, 2005). Moreover, continued growth of world trade and industrialization led to increased demand for raw materials and created a larger market application for freight transport. On the social dimension, immigration and urbanization led to the growth of cities and resulted in longer travel patterns (Geels, 2005). The result of both developments was a rapid acceleration of developments in the passenger and freight transportation industry. This includes changes in technologies and artefacts, but also changes in the social-cultural dimension around transportation. With respect to the cultural dimension, the perception of land transport changed radically as it became independent of human or animal power. Moreover, on the political dimension the First World War (1914-1918) and the Second World War (1939-1945) accelerated technological developments and expanded the market niche for air transportation. After the Second World War, by contrast, there was a rapid acceleration of technological developments in the mainstream passenger and freight transportation. The introduction of air transportation induced globalization even further, and hence facilitated world trade and economic growth to prosper.

5.3.2. Emerging High-Speed Transportation Regime

The high-speed transportation regime was non-existing during the beginning of the 20th century and gradually emerged through evolution of the land-based transportation regime and the revolution of air transportation. As a result, many elements around the socio-technical regime of high-speed transportation did not exist and therefore had to be created and linked together. From here, technical and institutional innovations facilitated the emergence of high-speed transportation in particular market niches.

Rail Transportation - Although high-speed rail transportation was not achieved until 1964, conventional rail transportation was the first kind of higher speed transportation and had a monopoly on long distance passenger transportation until the development of the automobile and aircraft in the early- and mid-20th century. After the emergence of electric rail transportation, however, it was the infrastructure and its costs that hampered the introduction of high-speed rail transportation. A major breakthrough around high-speed rail transportation occurred in Japan in 1964 when the first commercial high-speed train started operations between Tokyo and Osaka, the Tōkaidō Shinkansen.

Air Transportation – The pioneer era of aviation was characterized by several market niches that further facilitated technological development. The first market niche was military niche during the First World War. Shortly thereafter, small market niches for commercial aviation were created with early passenger and mail transportation between London and Paris in 1919. Moreover, air races were a market niche that was popular among spectators and fueled visions that aircraft would change a future society. Shortly thereafter, the Air Commerce Act of 1926 was aimed to regulate commercial aviation through setting standards and facilitations. Although commercial aviation stagnated during the Second World War, the development and production of aircraft increased and revolutionized post-war commercial aviation. Following technological development during the Second World War, the first commercial jet was the Havilland Comet starting commercial operations in 1952. From thereon, the Jet Age First civil 1958, DC-8 and the Boeing 707 in 1958. As a result, the cultural perception of air transportation changed from military and privilege of the rich towards a way of mass transportation. The major breakthroughs in the high-speed transportation regime were achieved with the first jet aircraft crossing the Atlantic in 1948 and the first direct flight to Australia in 1952. The speed and capacity of high-speed transportation changed rapidly with the first successful introduction of the jet engine.

5.3.3. Technological Niche Developments

The invention of the combustion- and electrical engine was rapidly followed by its application in the rail- and air transportation. The development activities were primarily driven by both World Wars.

Rail Transportation – Since travel speed had always been an important factor in transportation, the first series of demonstration projects on high-speed rail transportation were conducted in Germany from the early 20th century onwards. Although demonstrations on electric high-speed rail were successful, the infrastructure created barrier to the introduction of high-speed rail transportation. Nevertheless, these early developments were accompanied by some disasters such as derailments and head-on collisions. First high-speed rail ambitions were made when France and Germany were developing electric rail for higher speeds in 1954, thereby further pushing the limits of electrified locomotives. A year later, the French National Railways introduced yaw dampers to solve hunting oscillation and dynamic instability of bogies and consequently successfully demonstrated its capability of exceeding 300 kph for the first time.

Air Transportation – The early years of the 20th century also saw the breakthrough and incremental development of the aircraft. The pioneering era was characterized by testing different experimental configurations to acquire and master the principles of a powered controlled flight. During the First World War (1914-1918), the military market niche stimulated the first wave of technological developments. The period after the First World War was characterized by early technological development efforts on the jet engine commenced in Germany and Great Britain. The Second World War (1939-1945) accelerated these technological developments and directed research and development towards the technological breakthrough of instrument flying, radio communications and radar technology. But it was the introduction of the jet engine that revolutionized aircraft performance. After the Second World War, development on jet- and rocket engines continued and in 1947 Chuck Yeager surpassed the sound barrier. The principles of supersonic air transport were later applied to commercial market niche of the Concorde and the Tupolev.

Magnetic Levitation - Although conventional rail transport was a rather energy-efficient mode of transportation back in these days, global engineers were conducting extensive searches towards advanced transportation alternatives since the beginning of the twentieth century. The first working prototype of the linear induction motor was developed and patented by inventor Alfred Zehden in 1905. In addition, the idea of magnetic levitation as a means of transportation was first was conceptualized by Robert Goddard in 1905, who envisioned a transportation system between New York and Boston with vehicles suspended by magnetic forces and driven through pressurized or evacuated tubes (Goddard, 1909). In addition to his work, French engineer Emile Bachelet, proposed a repulsive levitated scheme and build a small-scale prototype in 1914. Moreover, in the context of alternative ground-based transportation, German inventor Hermann Kemper began his research on magnetic levitation technologies in 1922. The protective rights to "a suspensions railway with wheels vehicles, which were hovering along iron rails using magnetic fields" were granted by the Reich Patent Office in 1934. Nevertheless, his principles of a suspension railway could only be proved through a small-scale demonstration projects. The high performance electronic equipment necessary for the construction of a magnetic suspension railway system was not yet available for the upcoming years. Only during the Second World War, basic research on electromagnetic levitation continued when Eric Laithwaite developed the first full-size working linear induction motor in 1940. Nevertheless, with the rapid expansion of both rail- and air transportation, magnetic levitation technology remained shelved for the first decades of the twentieth century.

5.4.Episode 1: Rise of Magnetic Levitation Technology (1966-1977)

Now that the context from which magnetic levitation transportation technologies emerged is set, the first episode is characterized by the early research and development efforts of the magnetic levitation technology and the emergence of the Magnetic Levitation Transportation Innovation System (MLTIS) within the high-speed transportation regime.

5.4.1. Landscape Developments

In order to understand the origins of the research and development activities on maglev transportation technologies, it is necessary to recall the situation at the landscape level during the 1960s. The post-war global economy was booming and rising trade contracts between Europe and the United States stimulated further growth of the transportation system. From a technological perspective, the breakthrough of the jet engine in commercial aviation and the first high-speed rail services facilitated rapid expansion of high-speed transportation regime. With respect to the social dimension, this facilitated longer and more frequent travel patterns and eventually resulted in rapid globalization of the world economy. Nevertheless, the expanding transportation regime was also subject to various outside pressures. Although the rail- and air transportation revolutionized the transportation system during this episode, it had begun to experience technological, environmental and capacity limitations. Even though air transportation was conceived most economically viable for long-distance travel, costs were increasing rapidly due to rising fuel prices and other political developments, such as the global oil crisis. In addition, the conventional rail transportation system was believed to have reached its capacity limits. As a result, the incumbent high-speed transportation regime was heating up slowly. The growing mobilization trends and the emergence of environmental groups triggered the search for alternative transportation technologies. In order to meet the growing demands for high speed transportation, a next generation transportation mode was needed that would be energy efficient, environmentally acceptable, and that was capable of operating in the 300-500 km/h range. The quest for advanced high-speed transportation as a means for social change corresponded partially with another landscape development, the movement of technological utopianism during the first half of the twentieth century.

5.4.2. Breakthrough of High-Speed Transportation Regime (1966-1977)

With the introduction of the first HSR in Japan and the rapid expansion of commercial aviation, the emergence of the high-speed transportation regime took off. It revolutionized the transportation industry by allowing people to travel great distances in a matter of hours instead of days or weeks. Moreover, the aviation industry has seen an impressive growth for the last century. Particularly the introduction of the Boeing 747 brought a new functionality to the aviation industry: global mass transportation. Nevertheless, the maglev technology for transportation re-emerged in the context of a potential gap that came up between rail- and air transportation (Nieuwsblad van het Noorden, 1989). The gap emerged between HSR transportation around 200 kilometres per hour, and commercial air transportation around 800 kilometres per hour. This provided an incentive for research on maglev technology for transportation.

Rail Transportation –Japan was the first to launch HSR transportation system when it opened the Tōkaidō Shinkansen at the Tokyo-Osaka corridor in 1964. The operating speed of 210 km/h was not the only revolutionary factor Shinkansen. It also offered the availability high-speed rail travel to the mass public with high reliability, comport and safety. Although European developments on high-speed rail emerged during 1950s and accelerated shortly after the Japanese introduction, the first high-speed rail services did not start until 1981.

5.4.3. Early Maglev Developments (1966-1977)

Despite post-war commercial air transportation flourished and the idea of magnetic levitation for transportation became abandoned, a big search for dramatic improvements in both the speed and scale of transportation emerged during the 1960s. Although rail transportation system has proven track record of efficient services, alternatives have emerged in particular technological niches. As a result, magnetic levitation technologies for high-speed transportation were proposed in Germany, Japan and the United States. It is claimed that magnetic levitation systems can achieve higher speeds with lower energy consumption, have lower life cycle costs due to lower vibrations, and produce less noise compared to conventional wheel-on-rail technologies. With respect to its development, a major technological achievement was breakthrough of low-temperature superconducting wires and the breakthrough of transistors and solid-state power electronics the integrated circuit. As a result, the birth of the Magnetic Levitation Transportation Innovation System (MLTIS) took place when both German and Japanese government established the research and development programs on magnetic levitation technologies for high-speed transportation [+F1, +F2].

Germany – Starting point for the development in Germany was when Bölkow reopened research into magnetic levitation technology for transportation in 1966 [+F1]. In line with the search for alternative transportation technologies, the German Minister of Transport opted for alternative transportation technologies to address the traffic congestion issues in 1968 [+F4]. A small number of actors were involved and various research and development programs were set up [+F1, +F3]. As a result, state-funded research towards short-stator technology was performed by Bölkow, Deutche Bundesbahn and Strabag Bau [+F2, +F6]. Moreover, a feasibility study into high-performance high-speed railways was commissioned by the Federal Ministry of Transport in 1969. It included extensive searches towards improved steel wheel-on-rail technologies, air cushion levitation technologies, and magnetic levitation technologies [+F1]. The resulting pilot- and demonstration projects for short-stator technology were primarily directed towards knowledge development and exploring technical alternatives [+F3]. The first technology to challenge conventional HSR was the maglev technology with electromagnetic suspension. The history of the Transrapid dates back to 1969, when Krauss-Maffei starts construction of the first Transrapid 01 demonstration model [+F8]. About two year later, in 1971, the first electromagnetically levitated passenger carrying demonstration vehicle was presented at 660m track near Munich for Ministry of Transport developed by Messerschmitt-Bölkow-Blohm (MBB) [+F8].

Figure 16 - Transrapid 04 in München

Figure 17 - Thyssen Henschel HMB2

Krauss-Maffei succeeded rapidly with the development of the Transrapid 02 demonstration vehicle at the 930m Munich-Allach test track [+F8]. Although several government funded development programs were set up, transport Minister Riesenhuber decided to suspend government funding until private industry was willing to provide additional financial support. [-F4, -F6]. In 1972, development continued and Transrapid 03 demonstration vehicle based on short-stator principles and linear induction motor was presented by Krauss-Maffei. By contrast, a consortium by AEG-Telefunken, BBC and Siemens started research and development activities on electro-dynamic levitation systems with superconducting coils [+F1, +F2] (Gieras, Piech, & Tomczuk, 2011). As a result, the EET1 demonstration project was launched at a circular test track near Erlangen [+F8]. In 1973, the follow-up Transrapid 04 demonstration vehicle was revealed by Krauss-Maffei on the extended 2400m test track. In 1974, Krauss-Maffei and MBB decided to join forces and launched the Transrapid EMS. The next two years, Thyssen-Henschel presented the first functional long-stator demonstration project, the HMB1(1975) and the HMB2 (1976) both with a linear synchronous motor and electromagnetic suspension support on a 100m test track in Kassel [+F8].

Japan - The early technological breakthroughs were achieved by the early state-funded demonstration projects of the ML100 and LSM200 demonstrators in Japan [+F8]. In addition to Germany and Japan, by the 1970s, development programs on air cushion technology in the United States, the United Kingdom and France started. Nevertheless, the projects were halted as various demonstration projects [F8] showed that noise, power consumption and the additional weight of air-moving artefacts were considered negative [-F1]. In the United States, funding on maglev in the ceased in the mid- to late 1970s [-F6], Japan and Germany continued research and development on EML and EDL technologies.

5.5.Episode 2: Competing Technologies (1978-1996)

The second episode is primarily characterized by divergence of two magnetic levitation technologies. The development efforts in Germany focused on electromagnetic levitation technology, which utilized attractive forces electromagnets generating a controlled air gap. By contrast, the development activities in Japan focused on electrodynamic suspension technology, which utilized repulsive forces through superconducting magnets.

5.5.1. Landscape Developments (1978-1996)

The need for advanced high-speed transportation technologies has intensified in throughout the second episode as industrialized countries face serious problems in urbanized regions and intercity corridors. First, a social landscape development is related to highway congestion have become a more pressing problem as travel delays, economic damage and severe environmental contamination led to worsening conditions in the transportation system. Additionally, congestion is not limited to road transportation as the air transportation system also reaches its limits. This put more pressure on the rail- and air transportation regime that further stimulated development efforts of transportation alternatives within the technological niche.

Moreover, the oil crisis of 1979 was an important landscape development that triggered the expansion of the MLTIS as oil prices soared. In the 1980s, societal developments put pressure on the transportation system. A major environmental campaign that emerged in which environmental advocacy groups took major efforts to put air pollution and anthropogenic climate change on the political agenda. In response, new policies were announced and clean technologies were developed by the industry. A political landscape development is the privatization of the Japanese National Railways (JNR) in into the Japanese Railway Group in 1987. As a result, technology development of SCMaglev transferred to the private industry. On the political dimensions, the Community of European Railways accepted a proposal to build a European high-speed rail network to connect all major cities in 1989 (Geerlings, 1998).

5.5.2. High-Speed Transportation Regime (1978-1996)

The expansion of the high-speed transportation regime during the first episode was driven by expansion of air transportation. During the second episode, high-speed rail transportation expanded rapidly as high-speed wheel-on-rail progressed rapidly and technological advances in air transportation brought efficiency.

Rail Transportation – In 1981, France launched high-speed rail in Europe with the launch of the Train á Grande Vitesse (TGV) between Paris and Lyon. With operating speeds 270 km/h it attracted high demand right from the start. The air transportation industry lost half its demand to rail, including many previous car trips, newly generated trips, and the majority of airline trips on this intercity corridor. Although Germany lagged several years behind, the Deutsche Bundesbahn started the ICE demonstration project for Intercity-Express (ICE) high-speed rail in 1985. Eventually, the 250 km/h high-speed network was put into operation between Hannover and Würzburg in 1991, thereby strengthening the technological trajectory of conventional high-speed rail. Moreover, raising barriers for the emergence of the MLTIS.

Initially opened as individual lines, high-speed rail has now grown into a wide network by integrating lines between Spain, France, Germany and Belgium. As a result, magnetic levitation seemed to lose its superiority. First, recent developments in high-speed rail have reduced the advantage of magnetic levitation technologies in achieving higher speed. Second, high-speed rail has a large advantage over magnetic levitation due to compatibility with existing non-highs-speed rail networks. Third, the infrastructure construction costs for high-speed rail are lower while and operating savings for magnetic levitation are still highly uncertain.

5.5.3. Niche Developments (1978-1996)

The magnetic levitation transportation technologies can be broadly classified into two categories. For electromagnetic suspension, the electronically controlled electromagnets in the vehicle attract it to the magnetically conductive track. In contrast, electrodynamic suspension uses superconducting electromagnets or strong permanent magnets, to create a magnetic field that induces currents in nearby metallic conductors, when there is relative movement which pushes and pulls the train toward the designed levitation position on the guideway. Until 1977, technology battles in which short-stator versus long-stator technology and electromagnetic levitation versus electrodynamic suspension were competing for dominance

Germany – It was initially thought that short-stator technology would be less costly. Nevertheless, parallel developments on electromagnetic levitation and electrodynamic suspension technology were evaluated. In 1977, the German Federal Ministry of Research and Technology announced to support the long-stator and electromagnetic levitation technology and to abandon the both short-stator and electrodynamic suspension technology [+F4]. The announcement was followed by the decision to construct a demonstration track in Emsland [+F4, +F8] (Llerena & Matt, 2006)..As a result, research and development activities around the Transrapid move towards Emsland Test Facility (TVE) demonstration project [+F8].

In 1978, all research and development activities were consolidated under "MagnetBahn Transrapid" consortium by AEG-Telefunken, BBC AG, Krauss-Maffei, MBB, Siemens AG and Thyssen Industry AG Henschel [+F1]. As a result, construction work on the northern loop of the Emsland Test Facility (TVE) started in 1979. Moreover, Transrapid 05 is publicly demonstrated during the International Transport Exhibition of 1979 in Hamburg [+F8]. It is believed the high public visibility contributed to the positive expectations [+F4]. In 1980, construction on Transrapid 06 demonstration vehicle starts and the Emsland Test Facility starts pilot- and demonstration operations. As the development proceeds, ambitions to position the Transrapid technology in the global market transportation emerge [+F5]. As a result, the Transrapid International consortium is founded in 1981. In 1984, the first section of the TVE is completed and Transrapid 06 achieved an operating speed of 302 kmh. Three years later, the final section of the demonstration facility is completed and Transrapid 06 achieved an operating speed of 406 kmh. In 1988 the Transrapid 07 is introduced at the International Traffic Fair in Hamburg. Following a period of successful research and development on long-stator technology, the Deutsche Bahn A.G. confirmed technological maturity in 1991 [+F4]. As a result, the German government granted the development status to the Transrapid which allowed for the start of application and planning procedures. In 1994, it approved the start of the formal planning procedure of the Berlin-Hamburg route [+F1]. In 1995, public demonstration activities of the Transrapid 07 started.

United States – Although previous efforts were terminated in 1975, the Departments of Transport and Energy launched the National Maglev Initiative (NMI) to re-evaluate the possibility of incorporating maglev technology in the its transportation system (Geerlings, 1999). The objective was to evaluate the potential usefulness for maglev technology in improving the transportation system within the United States and to assess the role for the federal government in advancing it. In 1993, NMI presented its final report in which German and Japanese maglev technologies and high-speed rail alternatives were compared. In doing so, the report stipulated three alternative strategies. The first option was to adopt maglev technology being developed in either Japan or Germany. Alternatively, the second option was to launch an advanced development program in collaboration with either one of the countries as technology leader [+F2, +F3]. A third option was to initiate a proprietary advanced research program on magnetic levitation technologies.

Japan – In 1977, the Miyanzaki pilot- and demonstration facility with an inverted T-shape guideway was opened. During the first series of tests, the ML-500 demonstration vehicle achieves 132 km/h and 301 km/h, respectively. In 1979, the ML-500 demonstration vehicle reached a speed of 517 km/h. In 1980, the guideway is converted to a U-shape configuration and tests with the MLU001 start. An important technological breakthrough in the Japanese development was the discovery of a new, higher temperature superconductors in 1987. Because of a limited guideway length of the Miyanzaki facility, in 1989, JR Central decided to build new pilot- and demonstration facility in the Yamanashi prefecture [+F4]. Construction work on this 118 kilometer track started in 1990 and seven years later, in 1997, the pilot- and demonstration facility opened for pilot- and demonstration activities [+F8]. Following the opening of the Yamanashi pilot- and demonstration facility, the SCMaglev development gained the status of national-funded project in 1990. Despite the technology battle between German and Japanese technologies, Haruo Goto from JR Central in 1996 said that SCMaglev and the Transrapid, each with its specialties, can coexist.

5.6.Episode 3: Early Commercialization (1997-2012)

The third episode is characterized by the early commercialization efforts of both magnetic levitation technologies. One the one hand, the Japanese Railway Group opened the Yamanashi demonstration project to further develop the SCMaglev technology. Alternatively, following a turbulent period in which most proposals were cancelled, Transrapid saw its first commercial line being put into operation in Shanghai instead of Germany.

5.6.1. Landscape Developments (1997-2012)

During the 1990s, the economic relevance of new infrastructure projects was put on the political agendas by advocacy groups in many developed countries. As a result, high-speed rail projects were launched throughout Europe. However, societal protest from local residents and environmental groups grew, an through emancipation of society, greater political voice in societal decision-making processes was demanded. Public policies were no longer taken for granted and institutional changes gave citizens and societal groups more participatory power Geels (2007). For instance, the United Kingdom faces growing criticism towards a two-speed economy. As the largest consumer of energy, the energy crises from 2003-2008 also had its impact on the transportation industry. Although containing a single event, the accident at the Emsland Transrapid Test Facility (TVE) is regarded as a major landscape development that had widespread impact on the commercialization and adoption of the Transrapid technology. In September 2006, a Transrapid vehicle crashed into a maintenance vehicle, thereby killing 23 people that were onboard the Transrapid 09 demonstration ride. Although thorough safety investigation by authorities suspected a chain of human errors as root cause, the technological reputation of the Transrapid technology was questioned by society. Additionally, the global financial crisis of 2008 created a severe economic down-turn in many developed countries. As result, public spending on infrastructure projects was cut and maintenance on existing infrastructure was preferred. Nevertheless, critics argue that public investments in new infrastructure projects are crucial for economic growth recovery.

5.6.2. Rebound of High-Speed Rail Transportation (1997-2012)

In general, the high-speed transportation regime during this episode is characterized by a rebound of the high-speed rail transportation. Spain and France constructed over 3200 and 2600 kilometre on HSR, respectively. The potential speed advantage of maglev had been eroded by recent development in the conventional high-speed rail transportation. Although multiple Transrapid proposals were made, economic feasiblity could not convince governments to invest in high-speed maglev systems. For instance, in 2008, the German government abandoned plans to build a prestigious high-speed maglev link between the city centre of Munich and its airport. As Europe's high-speed rail network was expanding and global air transportation became focused on cleaner aviation, the high-speed transportation regime became more lock-in with respect to high-speed rail and air transportation. The marginal benefits of high-speed maglev system against the severe risks and uncertainties could not compete with the incumbent high-speed transportation regime based on high-speed rail and air transportation.

5.6.3. Market Niche Developments (1997-2012)

The niche developments in the third episode are primarily direct towards market niches.

Germany - In November 1999, the Chinese Ministry of Science and Technology and Transrapid International Inc. signed an agreement to conduct a cooperative pre-feasibility study for the construction of a demonstration line in China [+F1]. Subsequently, in June 2000, an agreement for a cooperative feasibility study for the Shanghai maglev demonstration project was signed between the Shanghai city and Transrapid International Inc. [+F1]. Following results of the feasibility study, a consortium was launched to construct first commercial line, mainly as showcase project to promote technology export. In 2002, the Shanghai Maglev Train was built as demonstration project for China to exemplify that technological benefits could also be implemented for longer distances across China [+F8]. Although the project has not been formally cancelled by the Shanghai government, the decision to extend the Shanghai line towards Hangzhou have been suspended as a result of operating losses and public resistance on noise nuisance and excessive ground. Instead, a decision was made which preferred conventional high-speed rail above maglev technology on the Beijing-Shanghai corridor was made [-F4].

In response to the failed Berlin-Hamburg proposal two alternative projects for a breakthrough of the maglev system were proposed; the Transrapid München and the MetroRapid between Dortmund and Düsseldorf [+F1]. Although 200 million euro was invested in the planning phase, the eight-year planning project cancelled after Hartman Mehdorn took office as CEO of Deutsche Bahn. According to the consortium, the Transrapid infrastructure costs are similar compared to conventional high-speed rail infrastructure Nevertheless, the Bavarian government announced plans for Transrapid will be cancelled due to severe cost overruns. The MetroRapid Dusseldorf-Dortmund project was abandoned too by in June 2003 [-F4, -F5].

In the United Kingdom, the UK Ultraspeed (UKU) was the most detailed proposal for the commercialization of the Transrapid technology on European soil. The proposal for Transrapid technology in the United Kingdom was submitted in 2005, but plans were rejected in 2007 and conventional high-speed rail was preferred [-F4, -F5]. In 2007, Transrapid 09, driverless operation was commissioned by Federal Ministry of Economics and Technology, part of the advanced development programs. However, after cancelling the last proposal industry experts argued that without a "showcase project", the Transrapid not viable [-F4, -F5]. As a result, the Transrapid consortium considered to stop operations and sell the technology to China [-F1]. ThyssenKrupp and Siemens plan to halt demonstration activities at the TVE from June 2009 onwards as technological research is finished and the Transrapid system is mature enough to put into operation.

Japan – In 2009, the Japanese Ministry decides SCMaglev technology is ready for commercial adoption and in 2011, the ministry gave JR Central permission to build and operate the SCMaglev system on the Chuo Shinkansen line between Tokyo and Nagoya [+F1, +F5]. The Yamanashi pilot- and demonstration facility was closed in 2011 as construction work started.

United States – Following the National Maglev Initiative during the early 1990s, the Department of Transportation conducted a survey to determine whether the private industry would be willing to support the development of a magnetic levitation transportation system able to compete with the Japanese and German systems [F1]. Additionally, the Maglev Deployment Program was set-up to examine whether magnetic levitation transportation technologies could contribute to a safe and efficient transportation system in the United States [F1]. In 2000, passive magnetic levitation was developed by Richard Post, InducTrack. In 2011, the Northeast Maglev (TNEM) was founded with the aim of realizing a high-speed maglev train between Washington D.C. and New York by bringing the Japanese superconducting maglev technology to America's northeast corridor.

PART D – SYNTHESIS

6. Discussion

6.1. Introduction

The case study empirically analyzed the build-up of the Magnetic Levitated Transportation Innovation System (MLTIS). In doing so, the MLP was used as an effective lens to observe particular functional patterns from a macro- towards a micro-level and examine the role of pilot- and demonstration projects. In this chapter, a synthesis and discussion on the theoretical and empirical analysis is provided. First, the observed patterns of cumulative causation in each of the three episodes are discussed. Consequently, the relative structural strengths and weaknesses that supported these virtuous cycles are classified as well as the impact these processes had on the reconfiguration processes. Finally, a renewed typology of the motors of innovation is presented.

6.2. Cumulative Causation

Following the idea that innovation system build-up accelerates through the interaction of system functions, this section describes the virtuous cycles that were identified during the three episodes. Note that vicious cycles were present but are not taken into account for this thesis. The objective of this thesis is to examine the role of pilot- and demonstration projects in accelerating the innovation system build-up and therefore does not focus on system break-down processes.

In the first episode (1966-1976), the system functions began to emerge and are primarily driven by external landscape developments. The early research outcomes [F3] stimulate positive expectations [F4] and triggered governments to initiate research and developments programs [F1]. Accordingly, these programs were characterized by the allocation of financial capital [F6]. The development programs enable more research activities and the results from different projects raised the technological expectations [F2, F4]. Additionally, technology developers initiated various lab-scale demonstration projects [F8] to demonstrate the first technical principles of their product [F3]. The outcomes of these projects were shared [F3] and further boosted positive expectations [F4] and the allocation of additional financial resources [F6].

The second episode (1977-1997) is characterized by the further strengthening of the virtuous cycles. Here, technology developers choose specific technological foci and initiate industrial-scale demonstration projects to demonstrate the technical and preliminary economic principles of their product in a commercial environment [+F8]. The research outcomes [F3] stimulate positive expectations among other technology developers [F4] and triggered more private actors to participate [F1]. Moreover, the public demonstration activities were vital to demonstrate the technology to a series of first potential adopters [F5].

Finally, the third episode (1998-2012) is characterized by the early commercialization efforts of the magnetic levitation technology as technology developers to launch deployment demonstration projects [F8] to boost positive expectations and attract early adopters. Nevertheless, the economic performance from feasiblity study remained poor and market proposal were cancelled due to a lack of public support [-F5].

6.3.Structural Configuration and Reconfiguration

There is a mutual relationship between the static and dynamic elements of the TIS. The system build-up processes, and thus the virtuous and vicious cycles, emerge and are shaped by the structural elements that are present at any given moment in time. Alternatively, successful build-up processes also contribute to the reconfiguration processes of these structural elements. The following section identifies the drivers and barriers for the structural configurations in each episode and, in turn, described what impact the build-up processes have on the structural reconfiguration processes.

6.3.1. First Episode (1966-1976)

Most of the activities during the first episode between 1960-1976 were related to [F2] Knowledge Development, [F3] Knowledge Diffusion, [F4] Guidance of the Search, [F6] Resource Mobilization, [F8] Pilot- and Demonstration and occasionally [F1] Entrepreneurial Activity. The following structural drivers, barriers and impacts were identified during this episode:

Structural Drivers – The first episode started with search for advanced transportation technologies. As the magnetic levitation principles as an enabler for high-speed transportation had already been demonstrated on an abstract level during the historical episode, the promise of an emerging technology holding a technological solution to address a common perceived societal problem was a primary driver during this first episode. As result, governments set-up research programs and set aside financial resources. Technology developers in the role of enactors initiate early research activities and lab-scale demonstration projects. Another driver was the growing sense of urgency related to these societal concerns. As a result, technology developers and research institutes took de role of enactors and were dedicated to further developing the magnetic levitation technology.

Structural Barriers – There were also a number of structural barriers that had to be overcome. A first barrier relates to the limited size of the enactor network, being small with selector support limited to the government. As a result, the activities in the first episode are primarily oriented towards the supply-side of the MLTIS and leave the demand-side relatively poor as both HSR and air transportation expanded. A second barrier is related fundamental uncertainty from a technological and an economic perspective. The first demonstration projects only allow for low-speed demonstration and could not reduce uncertainty on commercial operations.

Structural Impacts – The rise of a collective societal vision towards a future that provides sustainable very high-speed transportation reinforced the structural elements of the MLTIS. The introduction of research programs and pilot- and demonstration projects, contributes to the structural reconfiguration processes in the sense that positive outcomes led to an increase in promises and expectations, which in turn could boosted enactor participation and further drew in the interest of specific selector groups. Moreover, successful activities had lasting impact on the technological knowledge base, thereby strengthening the supply-side of the MLTIS.

6.3.2. Second Episode (1978-1996)

In addition to the activities that were present during the first episode, the activities during the second episode were also strongly related to the [F1] Entrepreneurial Activity and the [F7] Support from Advocacy Coalitions. The following structural drivers and barriers were identified during this episode:

Structural Drivers – Structural drivers of the second episode are primarily related to advances in technological maturity compared to the first episode. Following the lab-scale pilot- and demonstration projects during the previous episode, the technology is relatively developed but still in a pre-commercial stage and imperfectly aligned to incumbent institutional structures. However, these early demonstration results raise expectations and drive more actors towards the IS, especially demand-side technology adopters and venture capitalist who are triggered by a potential commercial environment that offers a fruitful business opportunities. Moreover, especially for large technical transportation systems, the national- and local governments could drive MLTIS as launching customer. The Japanese and German governments acted initially as a supportive selector. Once a decision was made for EML or EDS technology, they also took the enactor role.

Structural Barriers – Although the second episode was driven by competition, this feature also brought additional barriers to the IS. First, in order to achieve large-scale adoption, the MLTIS has to link-up with or overthrow the incumbent high-speed transportation regime. A structural barrier could be the technology capture by incumbent firms that are primarily interested in maintaining their competitive advantage they have in the incumbent system, thereby intentionally blocking the further system building activities. Although the technological maturity offers commercial deployment, it also suggests that the potential incremental innovations are limited the group of enactors and selectors supporting the technology is small.

Structural Impacts – The rise of a collective societal vision towards a future that provides sustainable high-speed transportation reinforced the structural elements of the MLTIS. The introduction of research programs and pilot- and demonstration projects here also contributes to the structural reconfiguration processes in the sense that positive outcomes led to a further increase in promises and expectations, which in turn could boosted enactor participation and further drew in the interest of specific selector groups. Moreover, successful activities had lasting impact on the technological knowledge base, thereby strengthening the supply-side of the MLTIS. A network, although with a limited number of actors, is established in which technological knowledge is shared. A governmental support program is set-up to support further research and development and pilot- and demonstration projects. The first industrial-scale pilot- and demonstration projects provided insights in technological and preliminary economic challenges and supports the decision to continue on one technology, in other words, the knowledge base is adapted to either EML technologies (Germany) or EDS technologies (Japan). Technological infrastructures are built, i.e. the Miyanzaki demonstration in Japan and the Lathen demonstration in Germany.

6.3.3. Third Episode (1997-2012)

In addition to the system build-up processes during the first two episodes, the activities during the third episode between 1997-2012 are also related [F5] Market Formation. The following structural drivers and barriers that facilitated these build-up processes as well as the impacts they had on these structural elements were identified during this episode:

Structural Drivers – One of the primary structural drivers is a near-mature technology. This was clearly illustrated as the German government already announced technological readiness whereas the Japanese government did this in 2011. In addition, the promise of first commercial projects also drove the innovation system build-up. In Germany, proposals were made for different deployment projects. Among these were the Berlin-Hamburg proposal, the MetroRapid proposal between Dortmund and Düsseldorf and the Munich Airport proposal. In doing so, enactors were trying to convince selectors to enter the innovation system. The introduction of the Shanghai Maglev Train was a first type of deployment demonstration project of the German Transrapid technology. Another driver relates to the networks in which the enactors were organized. These networks are powerful enough to attract a variety of selectors that is ready to invest. For instance, the Transrapid International consortium was set-up in Germany between different large firms.

Structural Barriers – Although the third episode was driven by early commercialization efforts, this feature also brought additional barriers to the innovation system. First, in order to achieve large-scale adoption, the MLTIS had to link-up with or overthrow the incumbent high-speed transportation regime. As the European high-speed rail network expanded rapidly and the potential economic and environmental advantages of maglev had been eroded. Although multiple Transrapid proposals were made, economic feasiblity could not convince governments to invest in high-speed maglev systems and high-speed rail was often preferred. As a result, a structural barrier relegates to the strengthening of the incumbent high-speed transportation systems, which could result in negative expectations and block further system building activities.

Structural Impacts – The structural impacts during this episode relate to the growing interests of both enactors and selectors to support the MLTIS. Especially with the consideration of transportation as a public good, the role of the national and regional government in the formation of an early market projects is crucial. The support of the government also has a positive structural impact as large incumbent firms are attracted. With successful deployment demonstration projects in place, the uncertainty on technological and preliminary economic challenges could be further mitigated and result in more successful technology adopters. However, the opposite was observed during the high-speed maglev case.

6.4. Proposed Motors of Innovation

With the results from the empirical case study, a renewed typology for the motors of innovation is created that includes the role of PDPs. The motors are described in terms of the dominant system functions and have a particular focus towards [F8] Pilot- and Demonstration Projects. Note that the original motors as conceptualized by Suurs (2009) were modified to fit the gap in the system functions that constitute the build-up processes of a technological innovation system.

6.4.1. Science- and Technology Push Motor

The event sequence of the new Science and Technology Push Motor, see Figure 18, again starts with positive expectations or technological promises [F4]. Once strong enough, governments could launch research and development programs and grant financial resources [F1, F6]. In turn, these development programs, boost scientific research activities and lab-scale demonstration projects [F2, F8]. The results are diffused through conferences, workshops and meetings and reinforce the expectations and promises [F3, F4]. In the next cycle, additional firms and research institutes join the projects and further support the small-scale technology demonstration projects [F1, F8]. The willingness of those organizations to participate in these risky ventures depends on the outcomes of the first cycle [F1, F4]. Positive outcomes could attract firms to invest in the project, thereby contributing to the expansion of the research program [F4, F6]. Negative outcomes, by contrast, may have the opposite effects [-F4, -F6].

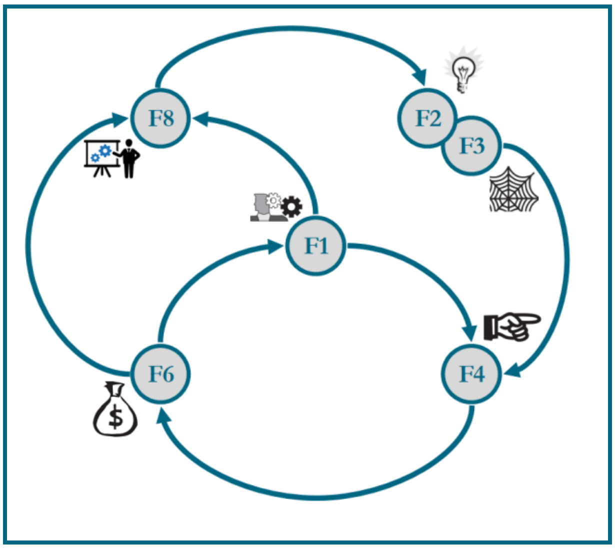


Figure 18 – New STP Motor

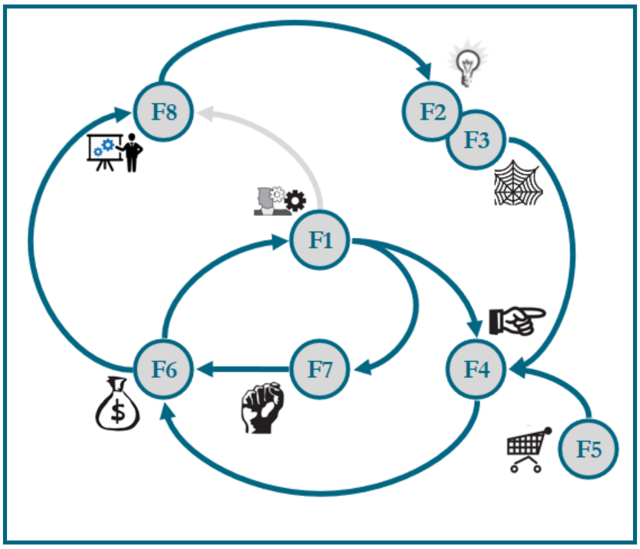


Figure 19 - New Entrepreneurial Motor

6.4.2. Entrepreneurial Motor

The event sequence of the new Entrepreneurial Motor, see Figure 19, starts with more enactors entering the innovation system and initiating innovative projects as they see opportunities for commercial or societal benefits [F1, F4]. The event sequence could be reinforced by the existence of first niche market activities [F5]. In the second cycle, given the immature technological character, enactors lobby the national government for financial resources to cover the costs and compensate the risks [F7]. If successful, subsidies are granted [F6] and industrial-scale demonstration project are started [F8]. The demonstration activities are now complemented by learning-by-doing activities and also provide preliminary economic feasibility. The result feeds back into the dynamic [F3] and provides stronger incentives for other actors to participate or refrain from doing so [F4].

6.4.3. System Building Motor

The event sequence constituting the new System Building Motor, see Figure 20, starts with technology developers and other actors that increasingly organize themselves in networks. These networks lobby the government for policies to mobilize resources [F6, F7] and regulations that reinforce the innovation system [F4, F7]. Most importantly, the aim of these lobby activities is to create an early market [F5, F7]. Once the resources are available, type IIIa technology demonstration projects are conducted to further improve the technical performance, set standards and develop market regulations [F5, F8]. Positive results from the technology demonstration projects are shared throughout the network [F3] and may raise expectations and draw in new enactors and selectors [F1, F3].

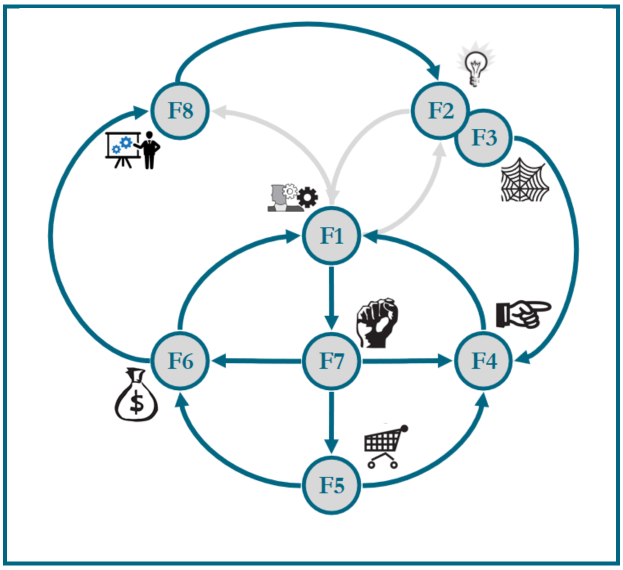


Figure 20 – New System Building Motor

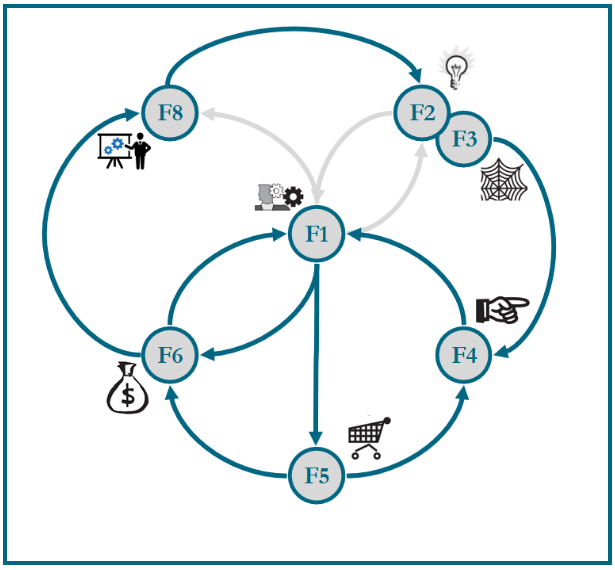


Figure 21 - New Market Expansion Motor

6.4.4. Market Expansion Motor

Although the Market Expansion Motor was not observed during the empirical case study, a new motor can be defined according to a similar processes that includes Technology Demonstration [F8]. Note that Support from Advocacy Coalitions [F7] is no longer present in this motor as Market Formation [F5] is part of regular business activities connected to Entrepreneurial Activity [F1]. The event sequence associated with the new Market Expansion Motor, see Figure 21, starts with the creation of additional institutional structures that facilitate further commercial demand [F1, F5]. First, A boost in expectations [F4] lead to wider entrepreneurial activity by new entrants [F1]. Secondly, the new entrants are likely to make large investments [F6] to set-up type deployment technology demonstration projects [F8]. These demonstration projects are aimed to reduce economic and organizational risks improving the system performance, reduce the operational costs, increase the efficiency along the value chains and get access to user know-how and experiences [F2]. This in turn further increases the expectations and demand for the emerging technology [F4, F5].

7. Conclusions and Recommendations

7.1. Introduction

The objective of the final chapter of this thesis is to come to a synthesis of all the insights obtained from the theoretical part of this study and the empirical information obtained from analyzing the case study. The second section presents the conclusions and answers the main research question comparing the case study results with the theoretical analysis and the conceptual framework. Consequently, the third section addresses the scientific and practical recommendations. Section four delineates the limitations of this research. Finally, section five concludes the chapter by reflecting this research on the Management of Technology program.

7.2. Conclusions

The idea followed throughout this research is that radical innovations emerge within the context of systems that consists of actors, institutions and technologies. Moreover, these innovation systems do not emerge in isolation but in turn emerge within the context of incumbent socio-technical regime and landscape developments. The objective of this thesis was to explore the role of pilot- and demonstration projects in accelerating the virtuous cycles of system functions, that is the motors of innovation, for emerging innovation systems. It is only once these system functions provide the emerging innovation systems with enough momentum that a breakthrough and technological transitions could be successful. Following the results of the theoretical and empirical analysis, the answer on how pilot- and demonstration projects could strengthen the motors of innovation of emerging innovation systems can be provided through the following set of conclusions:

- The first round of build-up processes, in the literature described as the science and technology push motor, is strengthened by emphasizing the technology demonstration function through lab-scale pilot- and demonstration projects. More specifically, the demonstration projects are focused on basic research and demonstrating the early technical feasibility. With limited resources in place, positive outcomes of these demonstration projects could result in a reduction of the initial technological uncertainties. The positive outcomes are diffused throughout networks, reinforce positive expectations, attract additional firms and research institutes who join and invest in the projects and thereby contribute to the first expansion of the research and development program. The activities could induce a first virtuous cycle and create an accelerating effect within the first motor of innovation.

- The second round of build-up processes, in the literature described as the entrepreneurial motor, is strengthened by emphasizing the technology demonstration function through industrial-scale pilot- and demonstration projects. More specifically, these demonstration projects are, in addition demonstrating applied research principles, focused on exemplifying the preliminary economic feasibility on an industrial scale. Although the technical feasibility is more reliable, the expanding actor group is more organized in networks and subject to increasing costs and risks. Especially for large technical system, governmental support and regulation is set-up to support further expand the emerging innovation system.

- The third round of build-up processes, in the literature described as the system building motor, is strengthened by emphasizing the technology demonstration function through verification pilot- and demonstration projects. More specifically, the verification pilot- and demonstration project is focused on demonstrating the technical and economic feasibility on a full system and commercial scale. As a result, the innovation system becomes slightly competitive with the socio-technical regime. The pilot- and demonstration project for Transrapid was successful in demonstrating technical readiness. In fact, the TVE facility was primarily capable of addressing for technological and safety. Even though maglev transportation technologies appear to have many technological advantages over conventional high-speed rail transportation, due to lack of commercial applications, the safety and economics needed to be further proved and demonstrated to potential adopters and users. Nevertheless, it did not succeed in demonstrating long-term economic prospects, leaving potential adopters with severe risks.

- It is important to note that the fourth motor of innovation, the market motor, was not observed during the empirical case study. Nevertheless, it can be concluded that the market motor could also be strengthened by incorporating the technology demonstration function. More specifically, the auxiliary demonstration project is focused on creating spin-off technologies for the commercial market environment. It is considered that a successful and mature market environment forces the innovation system out of the formative stage and into innovation system take-off.

7.3. Recommendations

Following the conclusions discussed above a number of recommendations are suggested.

Scientific Recommendations – This research has addressed the various roles of pilot- and demonstration projects in emerging innovation systems. In addition, the effect of landscape developments on the rigidity of the incumbent socio-technical regime is conceptualized and empirically tested. It is recommended to further test and generalize the successful breakthrough of emerging innovation systems based on two principal preconditions that have to be fulfilled. First, landscape developments have to facilitate increased pressure on the incumbent socio-technical regime to loosen its links. Secondly, the pilot- and demonstration activities have to anticipate system break through to alternating purposes along the innovation system development, moving from technical toward economic feasiblity. It is recommended for future research to perform cross case analysis to broaden the lens and include solar- and photovoltaic cell technologies, or hydrogen energy systems for instance. Moreover, future research should broaden the scope of industry experts as a source of information to fill the storyline gaps and check for factual errors or false interpretations.

Practical Recommendations – It is recommended for technology developers to acknowledge the changing roles of pilot- and demonstration projects and to consider the drivers, barriers and impacts it has on each of the motors of innovations for emerging innovation systems. Moreover, it is recommended for technology developers to consider a top-down and bottom-up approach. For the down-down approach, the changing landscape developments are powerful enough to put pressure on the incumbent socio-technical regime, thereby creating a window of opportunity in which the emerging innovation system can break through. More specifically, the technology developers around the hyperloop development need to consider the landscape developments that could provide both threats and opportunities. For the hyperloop development, landscape developments that boost or damage the high-speed transportation regime, such as the electric/hydrogen developments for air transportation, need to be monitored continuously.

For the bottom-up approach, by considering different roles of pilot- and demonstration projects, the virtuous cycles could be strengthened and directed from the science- and technology push motor towards the market motor. As such, the following roles of pilot- and demonstration projects should be recognized; prove technical feasibility, to set-up of knowledge and industry networks, facilitate learning processes, reduce costs, prove feasibility for commercial application, prove environmental feasibility, develop public acceptance and awareness, expose institutional barriers. Technology developers should focus on early commercialization on promising market niches, i.e. freight transport or high-capacity passenger corridors, as a showcase project are most crucial to market hyperloop technology to the rest of the world. Representative cost-benefit scenarios and the transparency thereof are important to potential adopters and is also related to medium-term and short-term economic prospects.

7.4.Limitations and Future Research

Although an ex-post assessment is considered best suited for analyzing the build-up processes within the innovation system, it has some limitations as well. The case study showed that accessing the situation too late might result in history having mellowed and some of the early events have been forgotten by the stakeholders involved. Particularly since the innovation systems on maglev transportation technology emerged in Germany and Japan, the available literature is limited and a complete narrative can be only restored only through the memories of those who have been closely involved to be objective about it. Another limitation is related to the scope of this thesis. Case study research through analyzing longitudinal cases studies is a laborious method. Since the time constraints of ths project are limited, it is not feasible to examine the case in great detail. Therefore, the results are valid for the innovation system of magnetic levitated transportation technologies and hence cannot be generalized directly. If the conceptual perspective holds true in multiple cases, it becomes more robust and results could be generalized. In order to generalize the results, however, it is necessary to combine insights from multiple case studies, thereby strengthening the results through the logic of replication. A third limitation is related to the accessibility of information. The literature on maglev technologies is primarily written in German, resulting is limited access to information necessary for the historical narrative.

7.5. Reflection on Management of Technology

The last section of this chapter is devoted to a personal reflection. The content of this research has very well reflected on the Management of Technology programme at the Delft University of Technology. First, the course on Technology Dynamics has a profound focus towards the characteristics of technical change. It considered the process of socio-technical change and how innovation can be steered towards socially responsive direction. Although the course considers social construction of technology and the evolutionary theory of innovation, incorporating lessons from the multi-level perspective could enhance the overall understanding of technical change within large technical system in society. Secondly, the course on Emerging and Breakthrough Technologies is concerned which innovation processes from a micro- and a macro perspective. Although the course was valuable to this thesis, the notion on functions and structures of innovation systems remains underexposed and could be more integrated in the course. Thirdly, the course on Technology, Strategy and Entrepreneurship was relevant for this research as it focuses on formulating and implementing a technology strategy for large firms. Particularly with respect to the different actor groups that were following a distinct set of strategies to research, develop and demonstrate the technology. Finally, the course on Intra- and Organisational Decision-making was also relevant as the decision-making processes on publicly funded pilot- and demonstration projects were complicated. However, when considering the notion of participatory decision-making, the decision-making processes around commercial maglev could have been elaborated in more depth. In sum, it can be concluded that the knowledge that was obtained during each of these courses have been at the core of this research.

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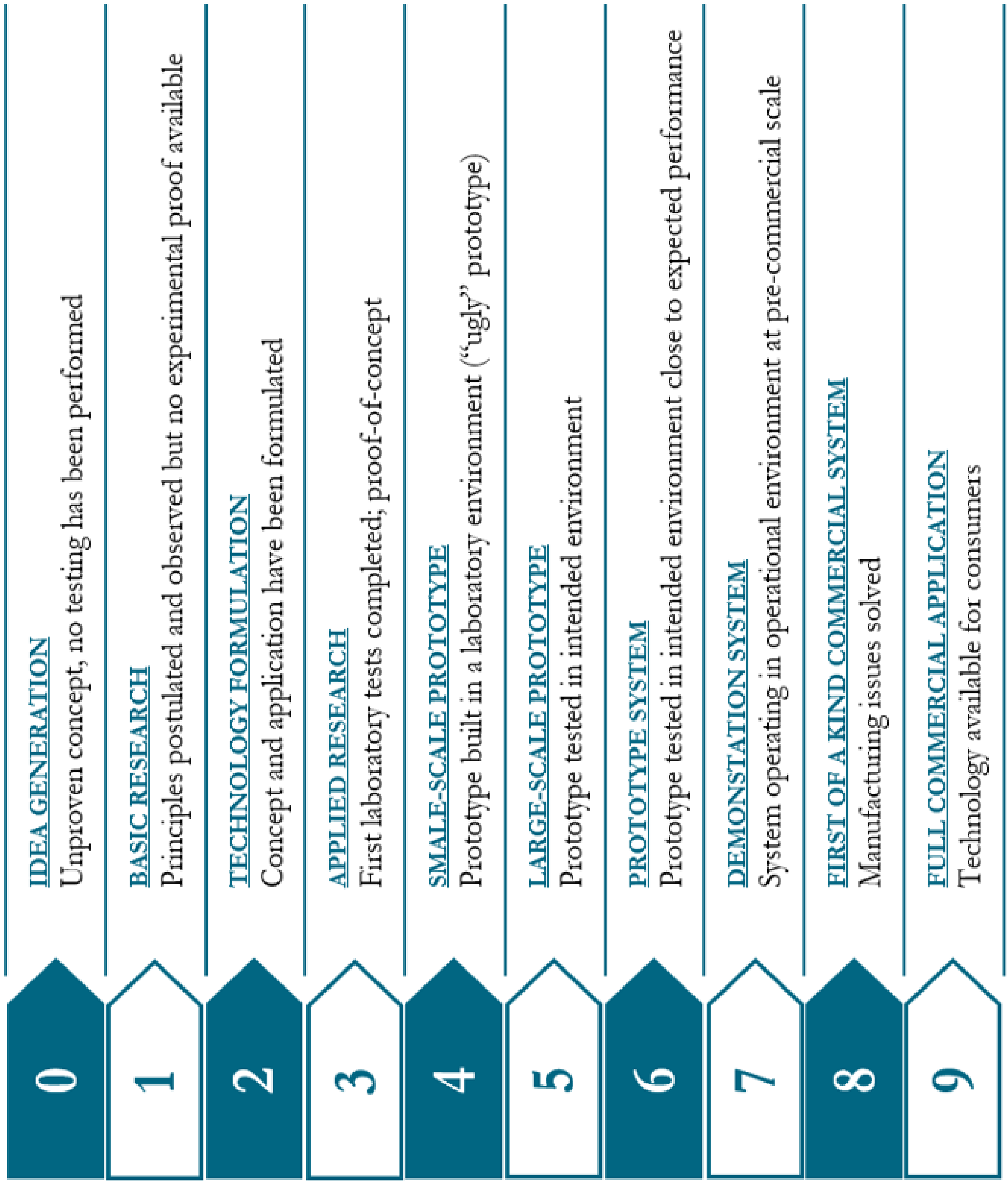
Appendix A. – Technology Readiness Levels



The Role of Pilot- and Demonstration Projects in Accelerating Hyperloop

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The contemporary transportation system is encountering drawbacks related to air pollution, noise nuisance and traffic congestion. Emerging sustainable alternatives based on magnetic levitation have emerged but failed to successfully breakthrough in incumbent regimes based on high-speed rail and air transportation.

Emerging innovation systems face difficulties in obtaining enough momentum necessary to break out of the niche level and induce a technological transition. Therefore, it is important to understand the changing roles that pilot-and demonstration projects have in the build-up processes of emerging innovation systems.

As a start, the role of pilot- and demonstration projects together with the state-of-the-art literature on innovation systems and technological transitions is analyzed. A conceptual framework is constructed and empirically tested with a longitudinal case study on the emergence of the high-speed maglev transportation innovation system in Germany and Japan.

In conclusion, the recognition of the changing roles of pilot- and demonstration projects along the motors of innovation together with anticipation of the landscape and regime developments could result in enhanced momentum for emerging innovation systems to break out successfully of the niche level.

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