Overcoming the Valley of Death

An industrial case study of barriers and enablers when using the Technology Readiness Level scale

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MASTER THESIS

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Abstract

An innovation process should take an idea all the way from research to the market. However, this is a long process in which many barriers can appear. For this thesis, a case study has been conducted, at a large Swedish industrial manufacturing company, with the purpose to examine their material innovation process.

They have experienced challenges when transferring the results of the innovation from Research and Development (R&D) to a receiving department. Too often, the findings of the R&D department are left on a shelf. Therefore, the purpose of the thesis is to identify which barriers that are present in the material innovation process at the case company, as well as to investigate best-case examples.

The challenges presented in the Internal Technology Transfer (ITT) literature often regard the communication between the R&D and Product Development departments. Furthermore, different ways of handling the barriers that appear in the innovation process have been found in the literature. For example, the Stage Gate (SG) process can be used to manage innovation.

The case company uses the Technology Readiness Level (TRL) scale. It is a tool to define the maturity of a technology development. The most prominent barrier found in the case study is *interface communication* at TRL 6 when transferring technology from R&D, also known as *the valley of death*. This refers to the communication and interaction between different departments within the case company. The *interface communication* in its turn consists of three main barriers: *not demanded technology*, *different resource prioritization*, and *insufficient handovers*, which is in line with the ITT literature.

However, the literature does not suggest if or how TRL and elements of SG could be combined. By mapping the process, barriers, and ways to address them, combining best case examples and literature findings, the authors fill this gap. A framework of how to incorporate the two concepts of SG and TRL is presented. Moreover, a recommendation of how other theoretical concepts could be added to the framework is given.

Keywords: Innovation Management, Technology Readiness Level, Technology Innovation, Internal Technology Transfer, Process Framework

Sammanfattning

En innovationsprocess ska ta en idé hela vägen från forskning till marknaden. Detta är dock en lång process i vilken många barriärer kan uppstå. För det här examensarbetet har en fältstudie gjorts på ett stort svenskt industriföretag, med syftet att undersöka deras materialinnovationsprocess.

De har upplevt att de möter utmaningar när resultaten av en innovation ska överföras från Forskning och Utveckling (FoU) till en mottagande avdelning. Resultatet från FoU lämnas alltför ofta på en hylla i detta gränssnitt. Därför är syftet med detta examensarbete att identifiera vilka barriärer som är närvarande i materialinnovationsprocessen på företaget, samt att undersöka exempel på när processen har fungerat som bäst.

De utmaningar som presenteras i litteratur om intern teknologiöverföring är ofta kopplade till kommunikationen mellan FoU- och produktutvecklings-avdelningen. Vidare har olika sätt att hantera de barriärer som uppstår i innovationsprocessen hittats i litteraturen. Ett exempel på detta är Stage Gate (SG)-processen som kan användas för att styra innovation.

Det undersökta företaget använder Technology Readiness Level (TRL)-skalan. Det är en skala som kan användas för att definiera hur mogen en teknologiutveckling är. *Gränssnittskommunikation* vid TRL 6 där teknologi överförs från FoU, även kallat *the valley of death,* är den mest framträdande barriären som har identifierats på företaget. Denna barriär refererar till kommunikationen och interaktionen mellan olika avdelningar inom företaget. *Gränssnittskommunikations-barriären* består i sin tur av tre huvudbarriärer: *icke efterfrågad teknologi*, *olika resursprioritering* och *bristfälliga överlämningar*, vilket är i linje med litteraturen om intern teknologiöverföring.

I litteraturen ges det dock inga förslag på om eller hur TRL och SG skulle kunna kombineras. Genom att kartlägga processen, barriärer och sätt att adressera dem, samt kombinera praktiska exempel med litterära resultat, fyller författarna denna lucka. Ett ramverk för hur de två koncepten SG och TRL kan inkorporeras presenteras i denna uppsats. Vidare ges en rekommendation av hur andra teoretiska koncept kan adderas till ramverket.

Nyckelord: Innovationsstyrning, Technology Readiness Level, Teknologisk innovation, Intern teknologiöverföring, Processramverk

Acknowledgments

The authors of this thesis are grateful for all the support and input that have been given to us during this process. The outbreak of COVID-19 took place during the period in which this thesis has been written. We therefore want to emphasize that we very much appreciate everyone who has taken their time to support the work with this thesis, despite the circumstances.

First and foremost, we would like to express our gratitude to the company at which we conducted the case study. A big thank you to everyone who has taken the time for an interview. The results of this thesis would not have been possible without you. We hope that all of you can somehow benefit from this study or find it meaningful.

Additionally, we would like to say a special thanks to our company supervisor Marcus Andersson, whose enthusiasm and support throughout the case study has been invaluable. Furthermore, a thank you to Anneli Sundblom who enabled the thesis, and whose spot-on input greatly improved the results.

Finally, we would like to thank our supervisor at the Faculty of Engineering, Kajsa Ahlgren Ode for the support throughout this process. Without your input and questions that made us further explain, and thereby better understand the data gathered, the results of the thesis would not have been the same.

Lund, May 2020

Linnea Håkansson & Johanna Wendesten

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List of Acronyms and Abbreviations

DRL	demand readiness level
ITT	internal technology transfer
KPIs	key performance indicators
Material Innovation	innovation of materials
MPD	manufacturing & process development
NASA	National Aeronautics and Space Administration
ONERA	Office National d'etudes et de Recherches Aérospatiales
PD	product development
PL	product line
PPM	Portfolio Project Management
R&D	research and development
R&T	research and technology
RTD	research technology development steel and steel processing
SG	stage gate
TL	technology level
TRL	technology readiness level

1 Introduction

This chapter introduces the background and subject of the thesis. The research questions, the purpose, and restrictions of the thesis are also presented.

1.1 Background

Research and Development (R&D) is a vital part of society and every large business. In 2017, the business enterprise sector of Sweden spent over SEK 120 billion on R&D (Swedish statistics, 2017a), which amounts for 1.5 percent of the total spending (Swedish statistics, 2017b). This is an increase with 8 percent from 2015 (Swedish statistics, 2017a).

Moreover, innovation is a critical component for companies to maintain and create a sustainable competitive advantage (Cooper, 1990). This is further strengthened by Magnusson and Johansson (2008) who argue that the incorporation of new technology into both new and already existing products is a crucial part of staying differentiated on the market. Thus, companies need to utilize their new technology in order to introduce innovative products, functionalities, and improved performance (Magnusson & Johansson, 2008).

However, there are challenges and barriers related to the introduction of new technology and innovation. These are, among others, lack of time, shortage of resources or staff, a short-term focus as well as lack of a systematic innovation process (Loewe & Dominiquini, 2006). In addition, Nobelius (2004) states that Internal Technology Transfer (ITT), the transfer of new technology from research to becoming a customer offer, can be challenging. At this stage, the responsibility for the technology should be handed over from the R&D department to the Product Development department (Nobelius, 2004).

This stage, the handover between R&D and Product Development is *the Valley of Death* investigated in this thesis. The challenges in at this stage can be, for example, difficulties in communication or a mismatch in prioritizations between the departments. It can also be difficult to define the maturity of the technology and at what point it should be transferred (Nobelius, 2004).

1.2 Issue of Study

The case study of this thesis has been conducted at a global manufacturer of bearings, seals, and lubrication. The company was founded in the 20th century and currently has approximately 43,000 employees allocated over 130 countries. It has 94 manufacturing units, over 17,000 resellers, and is active in several industries, such as pulp and paper, aerospace, automotive, marine, and railway.

Innovation of materials (Material Innovation) is an important part of staying competitive for the case company. A Material Innovation can be, for instance, an improvement of steel characteristics. The research and development of Material Innovations are conducted by the Research and Technology Development department for Steel and Steel Processing (RTD), which will be the department of focus for this thesis.

At RTD, development of a Material Innovation many times goes smoothly. However, when the Material Innovation shall be transferred to other departments, the challenges arise. This leads to the research sometimes being left on a shelf, never reaching the customer. Hence, it has been identified that the Material Innovation process is not successful for all initiatives. However, it is not known why, when, or which barriers that appear in the process, leading to difficulties in the transfer of technology.

Therefore, this thesis aspires to identify what the Material Innovation process currently looks like at the case company and why Material Innovations in some cases are left on a shelf at RTD.

Furthermore, the literature suggests different ways of handling challenges and barriers that appear in this part of the innovation process. For example, the Stage Gate (SG) process can be used to manage innovation (Cooper, 1990). Technology Readiness Level (TRL), which is used at the case company today, is another concept that can be applied, mainly to define the maturity of technology.

1.3 Research Questions

(1) What does the process for development of material innovations look like at the case company?

(1a) Which barriers exist in this process?

(2) How can the identified barriers in the process be addressed?

1.4 Purpose

The purpose of this thesis is to answer the presented research questions. This shall be done by mapping the process itself and identifying challenges as well as best practice examples. Furthermore, the literature does not suggest if or how elements of SG could be incorporated into the TRL scale to improve the use of it. This is a gap that the authors of the thesis aim to fill, by presenting a framework in which the two concepts are combined to address the identified barriers. In addition, a recommendation of how other theoretical concepts could be added to the framework will be presented.

1.5 Restrictions

The thesis is limited to the internal stakeholders involved in the Material Innovation process at the case company. Furthermore, the research proceeds from the perspective of the RTD department. Hence, the examined internal ways of working are those with their vantage point in RTD and their interaction with other departments. Three of the case company´s sites are represented in the case study: Gothenburg (Sweden), Houten (Netherlands), and Schweinfurt (Germany), since this is where RTD are located.

These limitations have been made to avoid that the scope of the thesis should become too broad, thus not being able to meet the purpose within the given time frame.

2 Methodology

In this chapter, the work process and character of the thesis will be described. First, the overall research method and work process are described. Thereafter, the data collection in the form of a literature review and interviews, as well as the method for analyzing the data, are elaborated on. Lastly, the credibility of the research is discussed.

2.1 Work Process

Qualitative research is research that, in general, is based on interpretations of situations and words rather than numerical data (Miles & Huberman, 1994). This method is considered appropriate when the goal is to understand *"how things work in particular contexts"* (Mason, 2002, p. 1). This thesis is explorative and aims to map an area of knowledge and information within the case company which, mainly, is based on employees' experiences. Hence, a qualitative-research method consisting of an interview study with a complementary literature review was chosen.

The overall work process for this thesis has followed the Double Diamond Model which is a model based on divergent and convergent thinking (Design Council, 2015), see Figure 2.1. Divergent thinking means a problem is explored and knowledge expanded. Thus, this form of thinking is illustrated as the first, widening, part of the diamond. On the contrary, convergent thinking is more focused and hence represented as the second narrowing part of the diamond (Design Council, 2015).

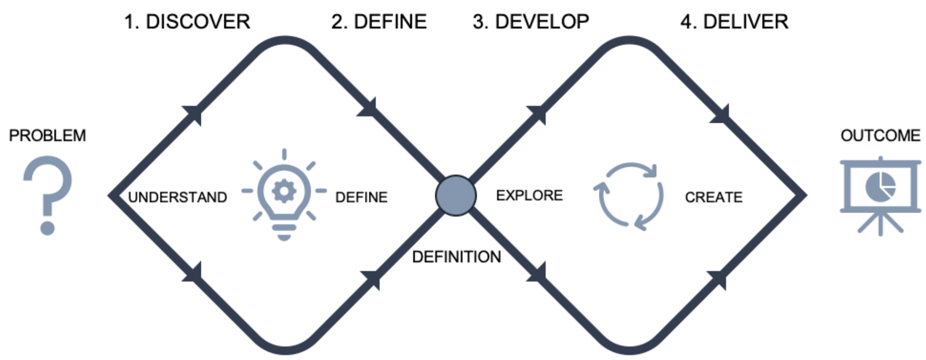

Figure 2.1 Double Diamond Model (Design Council, 2015; Schneider, 2015).

The first step of the model is called *Discover*. This is a phase of divergent thinking and at this step the focus should be to understand the problem while expanding the knowledge within the chosen field. Step two, *Define*, should focus on defining the problem and narrowing the scope with the use of convergent thinking. In the third step called *Develop*, possible solutions to address the problem should be explored, again, using divergent thinking. Lastly, the fourth step, *Delivery,* should focus on evaluating the solutions found and selecting which are best suited to address the problem (Design Council, 2015). What was done for this thesis during the four steps is described more in detail in Table 2.1. The time plan for the phases can be found in Appendix E.

Table 2.1 Activities conducted in each phase.

Discover *Understanding the problem*	***Define*** *Defining the problem and scope*	***Develop*** *Exploring possible solutions*	***Deliver*** *Evaluating and choosing solutions*
Initial literature review focused on innovation management	Further literature review focusing on Stage Gate and TRL	Literature review focused on addressing technology push and pull	Combined findings from interviews, documents and literature
Initial interviews to understand and discover principals and processes used at the case company	Further interviews to validate data from previous interviews and fill identified information gaps	Reviewed interview notes to identify practical examples of when the technology development has been successful	Matched identified best practice elements to the specified barriers
Searched the case company´s intranet for relevant information and documents with information about the innovation process	Synthesized empirical findings in excel	Reviewed interview notes to identify suggestions of improvements and process enablers	Created a framework of how to address the barriers
Mapped the processes at the case company	Mapped the problems and narrowed the scope by choosing focus areas		

Within each step of the Double Diamond Model, the research has been conducted with an iterative approach. This is illustrated in Figure 2.2. Each step included several iterations, focusing on conducting interviews with stakeholders at the company, reviewing literature related to the findings in the interviews, and analyzing the collected data. The analysis was the most central part of the work process and the authors returned to this activity frequently. In Section 2.2, 2.3, and 2.4 the methods for these three activities are described more in-depth.

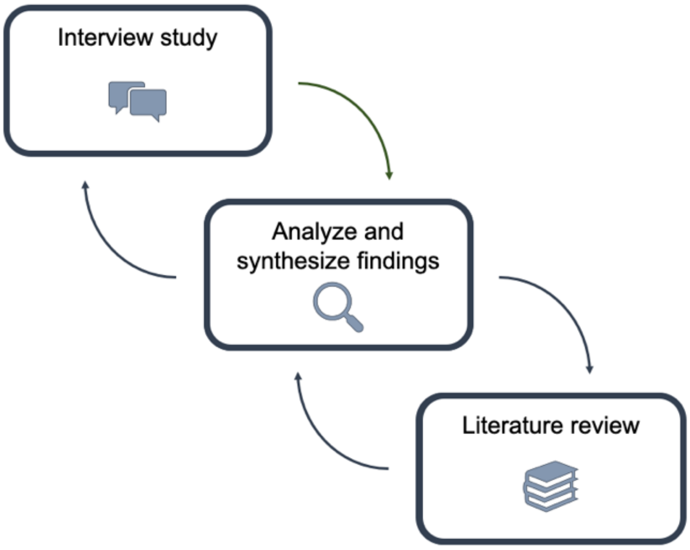

Figure 2.2 Iterative work process.

2.2 Literature Review

The literature review is the body of most scientific methods. It is used to map what has been done previously in the field of research, enabling the new research to build on existing knowledge and add a contribution. The review should continue throughout the research project and is preferably done in iterations (Höst, Regnell, & Runeson, 2006).

For this thesis, the literature review was conducted in a number of iterations, which match the process presented in Figure 2.2. The method of finding relevant literature was similar during all the phases.

Once the first, often very general, review had been conducted it was possible to define and search for more specific keywords. All references were logged in a spreadsheet where the keywords, library, and date of obtaining the reference were noted. By recording the keywords, the searches could become more and more refined as the review proceeded. As exemplified in Figure 2.3, the searches got more and more refined as the work progressed during each iteration. Furthermore, the list was used to go back and quickly review what had been previously covered, which made the searches more efficient.

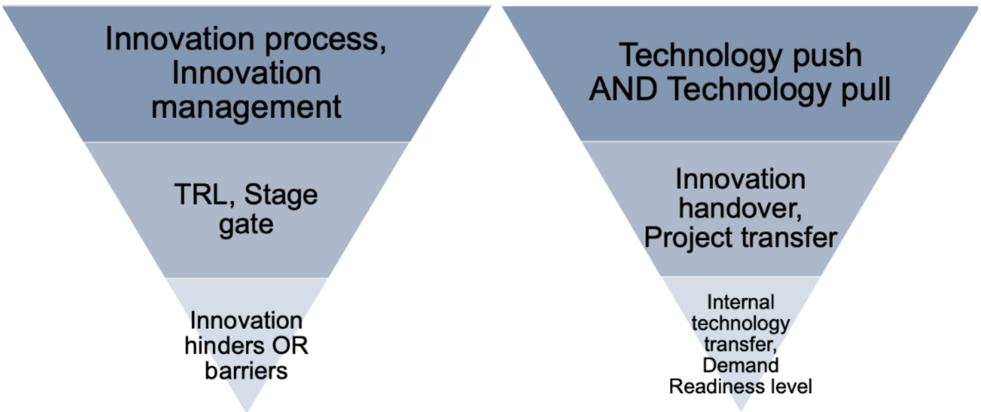

Figure 2.3 Search-word limitations for Discover and Develop-phases of literature review.

To further improve the work process, a summary column was added to the spreadsheet. In this column, a few sentences were written about what was found relevant for the thesis in the specific reference, as well as whether it had been incorporated into the report or not. This enabled a good overview of the literature obtained and used.

The databases used for finding academic articles, papers, and books were LubSearch, Scopus, and Google Scholar. In order to choose which literature to review the aspect of how many times a reference had been cited was used (Höst et al., 2006). Furthermore, new literature was found by looking into the references and citations of the articles already found and considered to be relevant. The review was finished when the same well-renowned references were found over again in the new articles read.

2.3 Empirical Data Collection

In this section, the method for how data have been collected at the case company is presented.

2.3.1 **Interview studies**

As previously mentioned, interviews were chosen to be an appropriate method to gather information for this thesis. Höst et al. (2006) suggest that the use of open interviews is appropriate when the study is of explorative character, as in this case. They describe that when the open-interview approach is used, the areas that should be investigated are fixed but the questions are open-ended and the order of which they are asked is flexible. The goal with open interviews is to explore an individual's perception of a certain situation, as in the case of this study (Höst et al., 2006). Thus, this approach was applied.

In line with the open-interview approach and the recommendations from Höst et al. (2006), an interview template was prepared with open-ended questions as well as follow-up questions, see Appendix A. The template was used to guide the interviews. However, when it was considered appropriate, questions were added as well as skipped. At the end of each interview, a check was conducted to make sure all necessary information had been collected and all relevant areas covered. Moreover, all interviews were conducted in four phases: (1) context explanation, (2) background questions, (3) main questions, and (4) closure, as suggested by Höst et al. (2006).

To get a comprehensive view of the Material Innovation processes at the case company, 25 interviews were conducted. It was ensured that all relevant business areas that are involved in the Material Innovation process were represented. Furthermore, all three sites where the RTD department is located have been represented. The specific interviewees were identified from recommendations made by both the supervisor at the company and his manager, as well as further recommendations that were given during the interviews. These recommendations were grounded in their experience and knowledge about which stakeholders are involved in, or affected by, the Material Innovation process. See Appendix B for a complete list of interviewees.

The interviews were conducted either in-person or by video call. During the video calls, screen sharing of documents and programs was often used to further enrich the communication of information. The choice of interview form was based on geographical distance. The sessions lasted 30 minutes to one hour depending on how much time was required to cover all relevant topics.

During the interviews, both interviewers were taking notes, most often by hand. These notes were compared, complied, and organized right after each interview.

Information that had been noted either by both interviewers or appeared repeatedly was taken into extra consideration and highlighted. The method used for the analysis is further elaborated on in Section 2.4.

2.3.2 **Documents**

Throughout the research, data have been collected from the case company´s internal documents. They have been found on the intranet as well as in the company's quality management system. The documents have been used as secondary sources of information to triangulate the data from interviews (Höst et al., 2006). This means that after a subject or a process has come up during an interview, more data has been identified using these sources of information.

2.4 Data Analysis

The data was continuously analyzed throughout the process, as recommended by Miles, Huberman, and Saldaña (2014). By doing so, decisions on which areas to focus the research on could be grounded in the data collected and analyzed. Since the analysis was based on information from interviews and literature, a prominent part of the analysis has been discussions between the authors of the thesis (Stake, 2010).

In order to formalize the thought process and discussions of analyzing the data gathered from interviews and research, thoughts, and ideas were recorded in a shared notebook. These notes concerned ideas of problem statements, possible solutions, areas that needed to be researched as well as topics for discussions (Stake, 2010).

The notes were taken whenever something came to mind and then discussed between the thesis' authors. Sometimes a note turned into a to-do and sometimes the ideas from these notes were dropped. Some of them immediately after discussions between the authors and some of them as new data were gathered proving the idea wrong or simply irrelevant. By having the ideas in writing it was easy to remember and be critical of conclusions made too early or based on not enough information (Stake, 2010).

In addition, content analysis was carried out after each interview (Robson, 2002). The terms used were discussed to note if they had been used in the same way and carrying the same meaning as in previous interviews or not. It was also discussed whether the new information was in line with what had been previously brought up. If this was not the case, another interview with someone who could potentially verify or dismiss the new data was scheduled.

To structure the data gathered, mind-mapping with post-it notes was performed. By visualizing the key-points brought up during each interview, it was possible to get an overview and mapping of the results (Stake, 2010).

During the process of analysis, it quickly stood clear that all barriers hindering a successful implementation were, in one way or another, related to the interfaces between departments. However, breaking down the problem and grouping the observations was a more difficult process than first expected. The first efforts of deconstructing the interface-problem led to Figure 2.4.

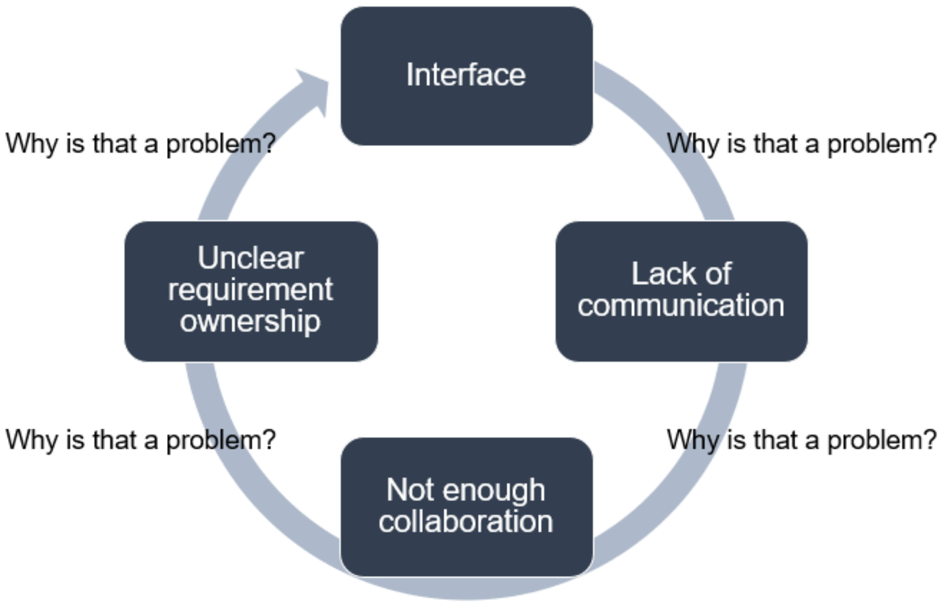

Figure 2.4 Analyzing the observations.

Starting with the problem *interface* and then asking, "*Why is that a problem?*", leads to the cause *lack of communication*, which in itself is a problem. Asking the question again leads to another cause likewise problem, and so on. The answers would eventually lead back to the starting point, creating a circle of reasoning.

In the search for a better way to analyze the observations, the structure presented by Gioia, Corley, and Hamilton (2013) was found. The principle presented in the paper on how to organize the analysis on three levels was applied. Working with the data in a table, going from *first order concepts* to *second order themes* and, thereafter, presenting an *aggregated dimension* gave clear insights. The detailed table can be found in Appendix C. In addition, the data was coded based on how many times the observation was brought up, which can also be seen in Appendix C.

The result of the analysis was the *aggregated dimension* and *second order themes* presented in Figure 2.5. These will be explained more in-depth in Section 4.3.

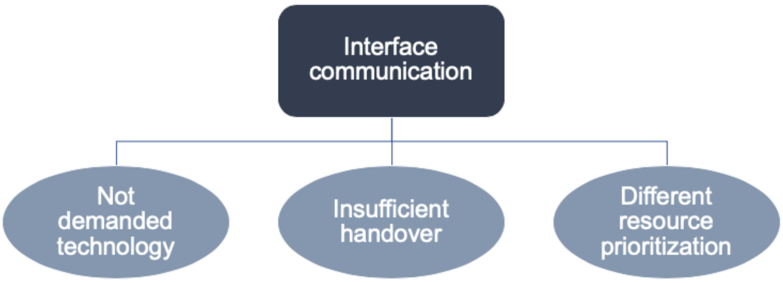

Figure 2.5 Aggregated dimension and second order themes.

To incorporate a time-aspect and visualize which barriers appear in which interface, the observations were also grouped on the three levels strategic, tactical, and operational. The levels were chosen since the terminology is well established in the literature (Schmidt & Wilhelm, 2000; Gutierrez & Serrano, 2008; Næss & Strand, 2015), in the industry in general as well as at the case company.

After having grouped and identified the barriers, the best-practice examples from the interviews and the reviewed literature were combined to create a framework. In accordance with Stake (2010) this was done by *"taking things apart and putting them together"* (Stake, 2010, p. 134). First, the sorted data from the interviews were analyzed to identify which elements that were common for all best-practice examples. Thereafter, these elements were combined in the framework. Furthermore, as the element of gating appeared to be prominent in all cases, parts of the SG process was incorporated into the final framework. Lastly, the framework was validated through cross-matching barriers with framework-activities to ensure that each barrier was addressed.

2.5 Credibility of the Research

In this section, the efforts which have been made to strengthen the credibility of the research conducted are discussed. Many of the efforts have been recommended by Höst et al. (2006).

Triangulation & feedback

According to Höst et al. (2006), several methods can be used to validate the quality and credibility of a study, whereof triangulation is one. Triangulation has been used in this research to validate the findings from interviews. This means that no conclusions have been drawn from a single source of information only. In order to draw a conclusion from data analyzed, the information it was based upon had to be represented in several interviews. As previously mentioned, the information collected during interviews was also validated through documents and process illustrations found on the case company´s intranet and in their quality-management system.

Moreover, feedback was used to further validate the data (Höst et al., 2006). This was done by presenting the information to the feedback givers, who then gave their response regarding if the information was in line with their perception of the situation or not. The feedback was mainly obtained from the thesis´ supervisor at the case company as well as his manager.

Avoiding biases

First and foremost, the authors early on made themselves aware of the risk of becoming biased as the research proceeded. The bias could either be toward some department or piece of information.

"All researchers have biases, all people have biases, all reports have biases, and most researchers work hard to recognize and constrain hurtful biases." (Stake, 2010, p. 165)

As recommended by Stake (2010), the authors of this thesis have had several strategies to minimize the effect of biases. The effects have been minimized, partly, by being explicit when discussing and processing information. Logging the work has been a good tool to achieve this. Additionally, Stake (2010) explains that over-simplification also leads to more bias than necessary. This has been considered when writing the thesis, especially when analyzing and visualizing the barriers in Section 4.3. The purpose of having the findings in a table as well as in several figures, was to not exclude parameters and the complexity of the issue.

Logging the work

Höst et al. (2006) suggest that continuously logging the work process and conclusions drawn throughout the research is a good way of ensuring the quality of the study's results. The authors of this thesis have logged and documented all relevant information, including interview notes, literature findings, and other thoughts, in a shared notebook. As mentioned in Section 2.1.3, the notes that were judged irrelevant were left untouched. This has made it possible to go back and review how and based on what information conclusions have been drawn. Moreover, the work process has been logged, both in a frequently updated overall-time plan and as more specified to-do lists regarding each week.

Literature selection

The selection of literature used in this thesis has been made carefully. Information presented in the results is exclusively based on academic journals. Furthermore, the number of citations has been considered to ensure the credibility of the references (Höst et al., 2006).

3 Theory

This chapter presents the main findings of the literature reviewed for the thesis. There are four main themes: Technology Readiness Level, Demand Readiness Level, Stage Gate, and Internal Technology Transfer.

3.1 Technology Readiness Level

In this section, the origin of the TRL scale is described, followed by sections where the modern use and critique of TRL are presented.

3.1.1 **Linear Model of Innovation**

The classifications which the TRL scale is developed upon derive from the Linear Model of Innovation. In 2006, Godin published an article in which he describes the Linear Model of Innovation as well as investigates where the model originates from. The basic concept is that research can be divided into four linear stages as presented in Figure 3.1.

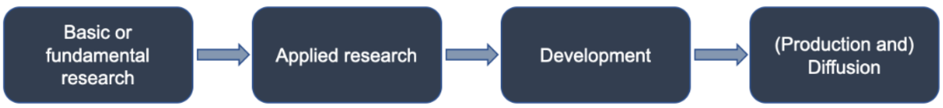

Figure 3.1 Visualization of definitions presented by Godin (2006).

In the article, Godin (2006) argues that the Linear Model has no clear origin in e.g. a scientific paper or article. In a paper by Edgerton (as cited in Godin, 2006) it is stated that:

"The linear model is very hard to find anywhere, except in some descriptions of what it is supposed to have been".

Instead, Godin describes that the model has developed over time in three steps. The first step took place circa 1900-1945. During this period, the definitions of *basic* research, as well as *applied* research, were introduced. These definitions were mainly introduced by researchers and scientists themselves to develop and define ways of talking about and describing what was done in the research which they conducted (Godin, 2006).

During the following years, the model developed by the addition of the definition's *development* and *diffusion*. Godin (2006) states that definitions were introduced by economics and social researchers to explain the transfer of research to business or social use. The paper continuously gives examples of how the model is taken for granted in research and innovation contexts (Godin, 2006).

Godin (2006) builds on Edgerton's statement and argues that the Linear Model was mainly introduced as a mean of classification. To start with, it was used and defined by the researchers themselves and since the 1930s it has been the foundation of how to allocate and trace the money spent on research. The model is a simplification of the process of research, which rarely is linear in practice.

An example of the simplicity of using the linear model as a mean of governance is how it was used as a framework for the NASA budget for many years. In an article published in 1979 it is investigated how the NASA budget has been allocated between the different classifications within Research and Technology, and how President Carter suddenly decided to stop funding the *basic* research and instead allocate all the money to *applied* research (Greenberg, 1979).

Godin (2006) concludes that the main reason why the model is still alive and widely used is that it describes research in a way that allows for clear statistics to be gathered. This statistic is often used to present the progress of the research conducted (Godin, 2006).

3.1.2 **The basic concept**

The concept of TRL originates from a National Aeronautics and Space Administration (NASA) paper published in 1989. The paper explains how NASA should work to better embrace a *"Technology push towards future space missions"* (Sadin, Povinelli, & Rosen, 1989). The authors describe how it has been challenging for researchers to get management commitment and resources to continue their research long enough for it to reach a level of usability for the space programs (Sadin, et al., 1989).

To address this issue, seven Technology Levels (TL) are presented by Sadin et al. (1989). The levels are a development and clarification of the classifications found in the Linear Model of Innovation. The TL scale is to be used to define which stage the research projects are in (Sadin et al., 1989).

In the original paper, Sadin et al. (1989) clarify that not all research must go through all seven steps of TL. For less critical applications of the research it is possible to go directly from a classification of e.g. level four to level seven. To clarify this, the term *Technology Flight Readiness* is introduced. It means that when a technology is flight ready, the innovation is considered stable enough to be put into a space rocket. The technology does not always have to reach the highest TL to be classified as flight ready. For some technologies, a TL of 5 could be accepted since it is not a critical component (Sadin et al., 1989).

Furthermore, the NASA Advanced Researched Technology program is after the introduction of TL divided into two types of programs: One program is called *Base* and it shall work with research at TL 1-4. The other type is *Focused programs,* with research within TL 3-7. Sadin et al. (1989) explain that there is an intentional overlap to facilitate the transfer of the research. Moreover, it is emphasized that the overlap of levels shall be used to enable better collaboration and hand-offs between the research and its application (Sadin et al., 1989).

The seven levels of TL are later expanded to nine, in a white paper published by Mankins (1995), see Table 3.1. This is done since the original seven levels were not nuanced enough when put into use. Additionally, the name is expanded to Technology Readiness Level (TRL) (Mankins, 1995).

Table 3.1 The updated NASA Technology Levels (Mankins, 1995).

Technology Readiness Level	***NASA Definition***
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and “flight qualified” through test and demonstration (ground or space)
9	Actual system “flight proven” through successful mission operations

3.1.3 **Horizon 2020**

Since the introduction of the TRL scale and the Linear Model of Innovation, the concepts have been applied to areas outside the technology sectors. In 2014, the European Commission accepted a new framework for funding of innovation and research projects, Horizon 2020. The purpose was to find ways of overcoming the financial crises by addressing challenges within the European Union and foster innovation (European Commission, 2014).

One of the three focus areas of Horizon 2020 is defined as *industrial leadership*. To describe the different phases of this area, the concept of TRL is used. In order to gain funds for the second phase of a research project, a TRL of 6 or above should be presented as a likely outcome of the phase (European Commission, 2014). The TRL scale has been slightly altered from the original definitions, it can be found in Appendix D (European Commission, 2019).

3.1.4 **Misuse of the TRL scale**

In an article published in the Innovation Journal, Héder (2017) expands on the topic: *"From NASA to EU: the evolution of the TRL scale in Public Sector Innovation"*. Héder (2017) introduces the topic of TRL and explains how TRL was introduced by NASA as well as the fact that it has been applied in the US Department of Defence in their process of technology acquisition. The article continues by stating that:

"From the very beginning, TRL was used to define boundaries between different organizational and financial modes of technological development" (Héder, 2017, p. 2).

The central argument of the piece is that it has never been established that the TRL scale can be used outside of NASA, or for anything other than means of a technology push process, which was the scale's original purpose (Héder, 2017). The author argues that since the first white paper about TRL was published many aspects of the scale have been *"…lost, forgotten and abstracted away during its journey to the EU*" (Héder, 2017, p. 3).

One example of this is the *Technology Flight Readiness*, which is not incorporated in the Horizon 2020 application of the scale (Héder, 2017). Another part of the TRL scale, that the author argues is often missing in the application of the scale in other contexts, is the NASA Integrated Technology Plan. In a document published in 1991, it is explained by NASA that the TRL should be combined with a *Technology Maturation Strategy*. The strategy's purpose is to define the collaboration paths between different departments. Furthermore, it is explained that the strategy is essential for a successful use of the TRL-definitions (Héder, 2017).

When discussing how the *Horizon 2020* program has interpreted the TRL scale, the author critiques that they have described it as *"the path from idea to market"* (Héder, 2017, p. 15). However, the creators of TRL do not claim to incorporate market needs (Héder, 2017).

In line with the findings of Héder (2017), a group of researchers at Luleå Tekniska Högskola published a paper in 2015 with the title *"A Technology Readiness level scale for iron and steel industries"*. They describe that the TRL scale has been a tool commonly used in the manufacturing industry since its introduction in the '1990s. However, when it comes to the process industry, and more specifically steel manufacturing, it is hard to apply the scale straight away. The main issues, described by Klar et al. (2016), are that the TRL scale does not incorporate the market needs and does not account for required changes to the already existing manufacturing process (Klar, Frishammar, Roman, & Hallberg, 2016).

3.1.5 **Adding dimensions to TRL**

Klar et al. (2016) state that in the process industry, a new product or technology often requires alterations in the existing manufacturing process. In the case of steel processing, the manufacturing process itself affects product quality and outcome. These aspects are not incorporated in the original version of the TRL definitions (Klar et al., 2016).

The authors therefore suggest further definitions of each level of the TRL scale, with more dimensions to be considered when defining the maturity for a technology. The proposed aspects to consider are *allowable location for trial, product dimension, manufacturing process dimension,* and *key questions/considerations for management*. The *key questions/considerations for management* include securing customer involvement in the later stages of TRL (Klar et al., 2016).

3.2 Demand Readiness Level

In an article published by Paun (2011) the Demand Readiness Level (DRL) scale is introduced. The paper is based on the author's experience from Office National d'Etudes et de Recherches Aérospatiales (ONERA), which is the French space research center (Paun, 2011). ONERA has a defined purpose to *"...develop and direct research in the aerospace field"* (Paun, 2012, p. 355). Furthermore, the author states that ONERA has a responsibility to *"transfer the results of its research to aerospace and outside of its field"* (Paun, 2012, p. 355).

ONERA has worked with the TRL scale since the 1990s. However, the technological transfer between ONERA's public R&D and Small Medium Enterprises still needs to be managed due to an asymmetry in how to they apply and develop technology (Paun, 2011). The author states that the activities at a research institute must be reshaped in order to reach *"equilibrium between Technology Push and Market Pull through a hybridized approach"* (Paun, 2011, p. 2).

However, it is not only the researchers who need to reshape their activities to reach the equilibrium. The Small Medium Enterprises and industries must also be able to express the demand in a way that makes it possible for the R&D unit to identify which research needs to be conducted in order to address it (Paun, 2012).

To address this need of expressing a demand, the DRL scale is presented by Paun (2012), see Table 3.2. The scale has nine levels and each level has a definition of how the needs of technology and research should be specified. The DRL and TRL scales have a matrix-wise relationship, meaning a TRL of 3 requires a DRL of 8, for the technology push and the market pull to work in synergy. As a rule of thumb, the sum of both levels should add up to at least 11 (Paun, 2012). The DRL definitions have been used in the industry to enable better communication regarding technology and the commercialization of it (Sutopo, Astuti, Purwanto, & Nizam, 2013).

Table 3.2 Demand Readiness Level scale (Paun, 2012).

Level	*Description of the Demand Readiness Level*	*Description of the TRL*	*Level*
1	Occurrence of a feeling 'something is missing'	-	-
2	Identification of a specific need in a given market	Certification and first sales	9
3	Identification of the expected functionalities for the new product/service	Product industrialization	8
4	Quantification of the expected functionalities	Industrial prototype	7
5	Identification of systemic capabilities (including the project leadership)	Field demonstration for the whole system	6
6	Translation of the expected functionalities into needed capabilities to build the response	Technology development	5
7	Definition of necessary and sufficient competencies and resources	Laboratory demonstration	4
8	Identification of the experts	Proof of concept	3
9	Building the answer to the expressed need	Applied research	2
		Fundamental research	1

3.3 Stage Gate

The Stage Gate (SG) process was created by Cooper (1990). He describes it as *"a conceptual and operational model for moving a new product from idea to launch"*. The model was created to increase the number of successful innovation projects launched. Cooper (1990) recognized that the creation of a new product is an actual process and, hence, can be managed. In order to create a successful innovation process creativity and discipline needs to be combined (Cooper, 1990). In the following sections, the model is described more in-depth. Then challenges with, and developments of, the process are discussed.

3.3.1 **What is the Stage Gate process?**

The SG process consists of gates and stages, as implied by the name. Cooper (1990) states that the number of stages and gates can vary depending on the company. However, a general skeleton of the SG process, which is applicable in a typical manufacturing company, can be seen in Figure 3.3 (Cooper, 1990).

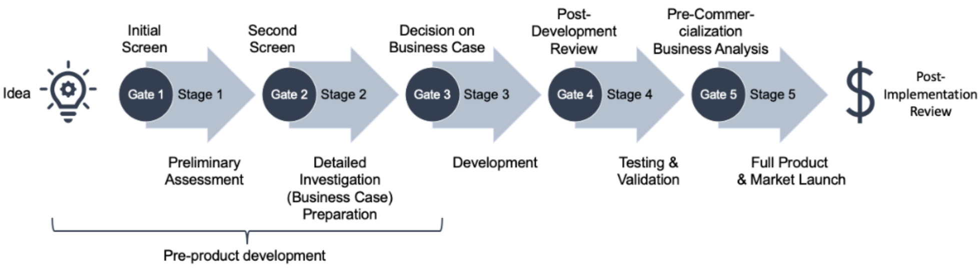

Figure 3.3 An overview of the Stage Gate System (Cooper, 1990).

The stages represent the parts of the process where the actual work is done (Cooper, 1990). Moreover, every gate is supposed to work as a control checkpoint with set quality criteria, deliverables, and specified output. At the gate appointed gatekeepers decide whether to go, kill, hold, or recycle the project. The gatekeepers should be senior managers who have the mandate to make this decision as well as allocate necessary resources for the next stage in the process. The costs and needed investments will increase as the project is moved further in the process (Cooper, 1990). In Table 3.2 a more thorough explanation of the SG system follows.

Table 3.2 Stage Gate in detail (Cooper, 1990).

Idea	The process starts with a new product idea.
Gate 1	Initial screen, the product idea is evaluated and the decision whether to start a project and allocate initial resources or not is made by the gatekeepers.
Stage 1	Preliminary assessment, this stage should not be too costly and not require much time. Preliminary market and technical assessments are made to form an understanding of the possible market of the product and the feasibility of the production of it.
Gate 2	Second screen, the project is evaluated with regards to set criteria and the information collected in stage 1. At this stage, the possible financial return of the project is also briefly evaluated. If the project gets a go-decision at this gate it moves on to a more costly stage.
Stage 2	Definition, here the project should be clearly defined, and the attractiveness of it evaluated by market research, a competitive analysis, and a financial analysis. The "do-ability" of the technical aspects of the project must also be evaluated.
Gate 3	Decision on business case, this is the last gate where the project can be killed before moving on to heavy spending. The information from previous stages is analyzed. In addition, the actual activities and how they were performed in stage 2 should also be evaluated before reaching a kill or go decision. Furthermore, the gatekeepers should define the project scope including the target market, product concept, and positioning strategy.
Stage 3	Development, the product is developed and the financial analysis updated. Moreover, patents and legal issues should be handled.
Gate 4	Post-development review, the output from stage 3 as well as the quality of the work is reviewed. The plan for validation in stage 4 is approved and the marketing and operations plans assessed.
Stage 4	Validation, the whole project should be tested with regards to the product itself, the production process, customer acceptance, and the financial aspects. This can be done through various activities, for example by conducting a pilot of the production and updating the financial analysis.
Gate 5	Pre-commercialization decision, this is the last gate, and hence, the last point at which the gatekeepers can decide to kill the project. A central part of this decision lies within the financials of the project. Furthermore, the marketing and operations plans should be approved for implementation in the next stage.
Stage 5	Commercialization, at this stage the marketing and operations plans should be implemented.
Post-implementation review	At this point, the project should be wrapped up and evaluated and the product should from here on be part of the company's regular product line. Furthermore, the financial outcome of the project should be compared to the analysis from previous stages. Lastly, a "post-audit", where lessons learned from the project are identified, should be conducted.

The SG model places much emphasis on the importance of creating a process without gaps (Cooper, 2008). The process should have a clear market orientation and much focus on the predevelopment of a product. It is also important that all stages are cross-functional to achieve a successful process (Cooper, 2008).

The SG process has many advantages, a few being that the use of it can shorten the time to launch, decrease the need for rework in the process and lead to a more successful development effort (Cooper, 1990). Overall, the model has been shown to have a positive impact on the success of the development and launch of new products (Cooper, 2014).

3.3.2 **Challenges with the Stage Gate process**

Cooper (2008) has identified some specific challenges with the SG process by observing when it has been used in practice. One of the main difficulties is to understand the scope of the model and how it shall be used. It is important to understand that the SG process is not a set of rules or a linear system, but rather a roadmap of how to get from point A to point B (Cooper, 2008). However, the process should be viewed as a way of allocating resources and follow up on the innovation process, not a bureaucratic control mechanism. Cooper (2008) further highlights that it is of great significance to keep the flexibility of the process and that when detours are necessary, they are allowed. For example, all projects might not need to pass all stages or gates and activities can be moved between the stages.

Furthermore, it has been seen that it can be challenging to appoint appropriate gatekeepers and form a proper understanding of their responsibility Cooper (2008). recommends that the seniority of the gatekeepers should be based on the resource need, size, and risk of the project. For example, if the project requires resources from several business units, which is often the case as the process should be cross-functional, the gatekeepers might need to be on a group management level to have the proper mandate to allocate resources. For major projects, the gatekeepers for gate 1 and 2 could be on a mid-management level. Then from gate 3 to 5, he states that they should be more senior since the need for resources increase. Correspondingly, the gatekeepers for a smaller project could be less senior. Furthermore, it is important that the information presented to the gatekeepers at the gates are not excessive. The commitment required for the stage ahead as well as the risks with a go-decision are the most essential information for the gatekeepers to get (Cooper, 2008).

Lastly, one of the highlighted challenges with the SG process is that the function of the gates is forgotten. Cooper (2008) refers to this as *toothless* gates. He describes that it is of great importance that the decisions at the gates are made carefully and that the gatekeepers do not let a project slide past a gate too easily. The go or kill are decisions that must be made at every gate, not just at the first one. That the project has passed Gate 1 does not mean that it cannot be killed at a later gate (Cooper, 2008).

3.3.3 **Development of the process**

To adapt the SG process to the specific project and organization, and handle some of the challenges previously mentioned, the original model has been developed further. Firstly, the model should be regarded as scalable, which means that the number of stages and gates in the process can be adjusted depending on the size and risk of the project (Cooper, 2014). Figure 3.4 shows three well-known adaptations of the model, where the five-stage version is supposed to be used for major and complex projects, the light version should be used for projects with moderate risk, and the express version for small development projects (Cooper, 2014).

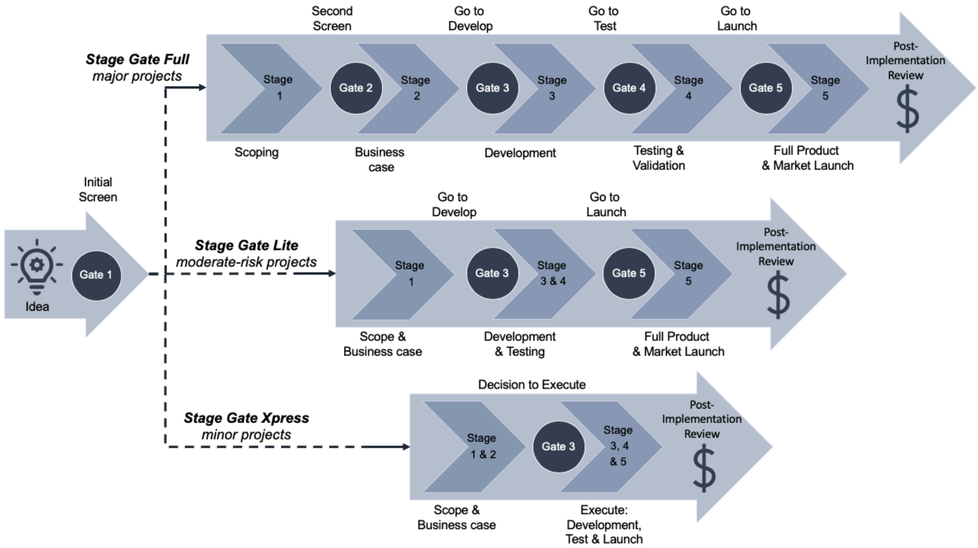

Figure 3.4 Adapted versions of the Stage Gate process (Cooper, 2014).

3.4 Internal Technology Transfer

Technology transfer is the general transfer of technology and knowledge from one stakeholder to another (Nobelius, 2004). It most often refers to the transfer on a high level, from one organization to another, for instance from a government institute to an industry (Nobelius, 2004). On the contrary, Nobelius (2004) describes that Internal Technology Transfer (ITT) focuses on the internal connection between R&D and Product Development. It is about how to incorporate research into a product to create a customer offer (Nobelius, 2004). Eldred and McGrath (1997, p. 41) state that:

> *"Realizing the promise of new technologies through their commercialization into new products is far from easy. Products utilizing a significant new technology require technology development prior to product development. These two processes are closely linked and typically require a technology transfer step as a bridge between them"*

ITT is seen as a central part of managing a firm's innovation since many barriers can be derived from the interface between R&D and Product Development and it should be treated as a continuous process, not isolated moments of time or single actions (Nobelius, 2004). New technology is often left on the shelf at the R&D department as a result of changes in the company's priorities or strategy during the research and development phase (Grimpe, 2006). Furthermore, the communication between R&D and Product Development is described as a barrier for ITT (Nobelius, 2004). The employees within these departments often have different backgrounds and knowledge and thus use different languages, creating difficulties in the understanding of each other (Drejer, 2000).

Moreover, Nobelius (2004) states that the R&D department and Product Development department often have different goals, which results in a mismatch. The focus within R&D is usually to develop knowledge, whereas Product Development focuses on launching products and creating customer offers (Nobelius, 2004). He further argues that the timing of technology transfer can be problematic since it can be difficult to decide when a technology is mature enough to be transferred from research into a product. The risk of incorporating a technology too early needs to be weighed against the possible time-loss of keeping the technology within R&D too long (Magnusson & Johansson, 2008).

3.4.1 **ITT framework**

Eldred and McGrath (1997) introduced a framework that is related to ITT. They argue that for the transfer of technology to be successful, three dimensions must be addressed: *strategic and operational synchronization*, *transfer scope*, and *transfer management*, see Figure 3.5.

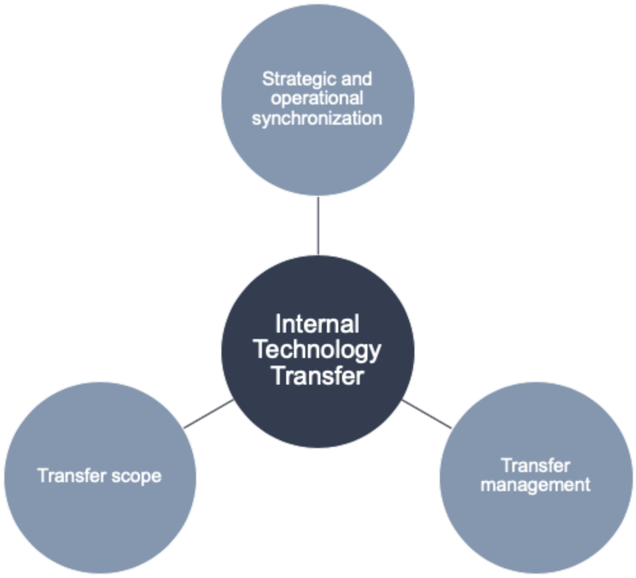

Figure 3.5 Visualization of dimensions presented by Eldred and McGrath (1997).

This framework is used and strengthened by Nobelius (2004) and Magnusson and Johansson (2008). They describe that the *strategic and operational synchronization* refers to the synchronization between R&D and Product Development. Their strategies and goals need to be in line with one another. The *transfer scope* is about what the delivery and transfer should include and how mature the technology should be at this point. Lastly, the *transfer management* concern who should be involved in the transfer as well as how it actually should be done (Nobelius, 2004; Magnusson & Johansson, 2008).

4 Results

In this chapter, the current Material Innovation process, involved stakeholders, and barriers identified from the empirical observations are described. Thereafter, a framework that expands the existing process and thereby addresses the identified challenges is presented.

4.1 Process Description

In this section the process for Material Innovation at the case company is described. There is a formal process described as well as established ways of working, which will be presented. It shall, however, be noted that innovation is not a linear process and each development of new technology is different.

4.1.1 **Theoretical process**

At the case company, the activities conducted throughout the Material Innovation process are described in relation to which TRL the research is defined as. For example, at TRL 3 the technology concept should be optimized. The input into the process is *knowledge needs* and *solution needs*, meaning that depending on the level of TRL the type of input is different. The process is presented in Figure 4. 1.

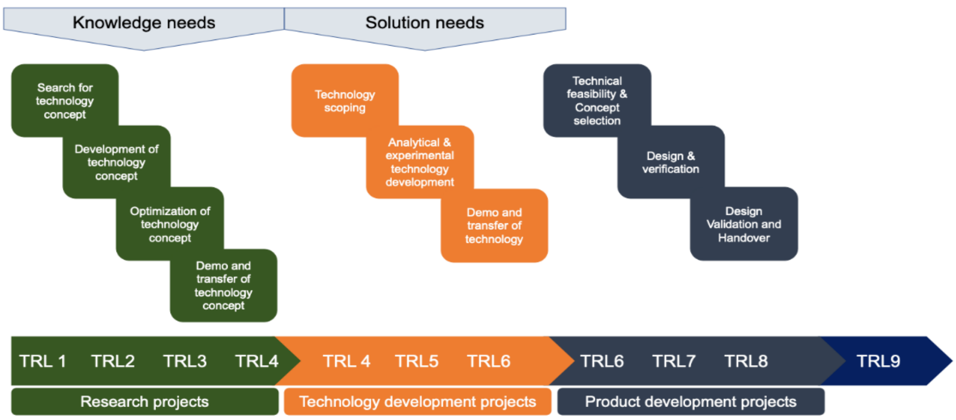

Figure 4.1 Innovation process as described in the quality management system.

The TRL scale at the case company is often grouped into four stages: 1-4, 4-6, 6-8, and 9, as can be seen in Figure 4.1 above. The TRL-groups are based on the type of projects that are conducted. For instance, on the first levels, the focus is on development of technology as a concept with no specific application in mind. As a technology starts to reach TRL 4, the development reaches a new stage and the technology is often developed and tested for various products in a laboratory environment. When reaching TRL 6, the research shall be transferred into a product development project. At this stage, the development is focused on design and validation.

4.1.2 **Interfaces**

The Material Innovation process presented in Figure 4.1 has three technology transfer interfaces, at TRL 4, 6, and 8. In Figure 4.2, the process is combined with the departmental responsibilities, as they have been described in the interviews conducted.

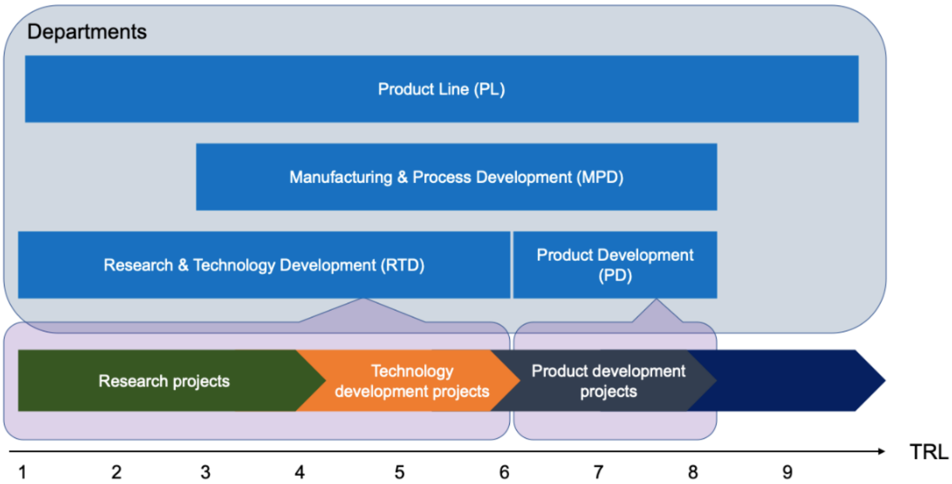

Figure 4.2 Department scopes and interfaces.

As shown in the figure, each department has a defined range of the TRL scale, which its operations should focus on. For instance, RTD focus on levels 1-6 and Product Development (PD) on levels 6-8. Product Line (PL) are active at TRL 1-9 since their role is to have a strategic input throughout the Material Innovation process. Likewise, Manufacturing & Process Development (MPD) have a strategic input to RTD, but they also have innovations of their own at TRL 3-8.

The first technology interface in the Material Innovation process occurs at TRL 4 and thereby takes place within the scope of the RTD department. The second one takes place at TRL 6, and here the technology development shall be transferred from RTD to a different department. The most common receiver for Material Innovations is the PD department. During the interviews, most barriers have been mentioned when talking about the need for transferring technology at TRL 6. Thus, this interface is the focus of the barriers and best practice presented in the later sections.

4.2 Stakeholders

To get a better understanding of the process described above, the stakeholders involved must be known. The RTD, PD, MPD, and PL departments are the ones that have been the focus of this thesis and where most of the interviewees are employed. The location, in the organization, of each of these departments is shown in Figure 4.3.

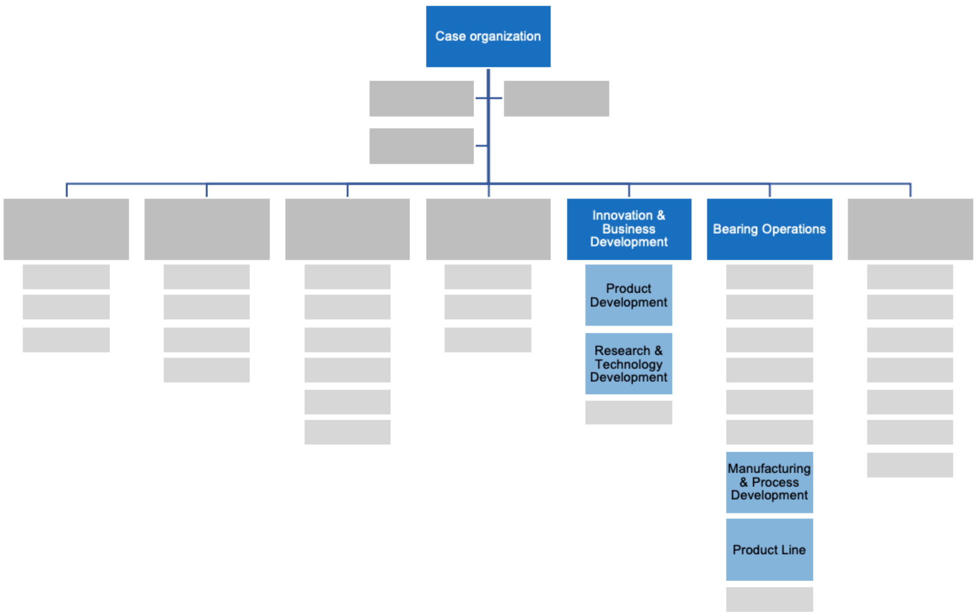

Figure 4.3 Organizational chart of the case company.

4.2.1 Research and Technology Development

The department for Research and Technology Development is made out of several teams, see Figure 4.4. The interviews conducted for this thesis has mainly been focused on the people working in Steel & Steel Processing, since this is the only unit which works with Material Innovations. Furthermore, it is the department which initiated this thesis.

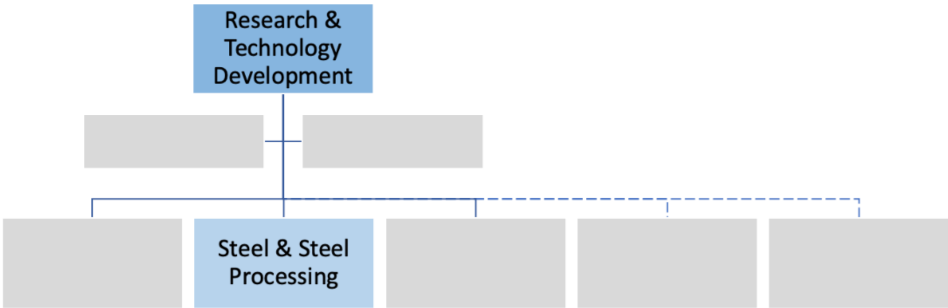

Figure 4.4 Organizational chart for RTD.

The day-to-day activities at RTD can be divided into three groups:

- Business support
- Research (TRL 1-4)
- Technology development (TRL 4-6)

Business supports are activities where RTD assist in applying already existing technology at the customers. Examples of these activities are to service the application engineers at PD when selling products to a tougher application than normally or to support in the identification of the cause as to why a bearing broke at a specific application.

Within the activities of research as well as technology development stated above, the Material Innovation takes place. The activities conducted within these stages of the TRL scale have previously been described in Figure 4.1 in Section 4.1.1. The results of each of the two phases are technical reports which are stored in the RTD archive. The abstracts are accessible to all people at RTD, PD, and MPD. However, in order to access the full reports, a request must be sent.

RTD consist of technology specialists within different areas of metallic handling. Most of the researchers have a PhD and have worked within RTD at the case company for more than 20 years. They all have strong networks within material development at the company and are based at three sites: Gothenburg (Sweden), Houten (Netherlands), and Schweinfurt (Germany).

4.2.1.1 Project and portfolio management at RTD

Within RTD the research and technology development are conducted in projects. A project can either be run independently or as part of a program. A program consists of several projects, which together shall reach a defined deliverable. In order to keep track of projects and programs run, they are all gathered in a portfolio. Figure 4.5 visualizes the relation between the three.

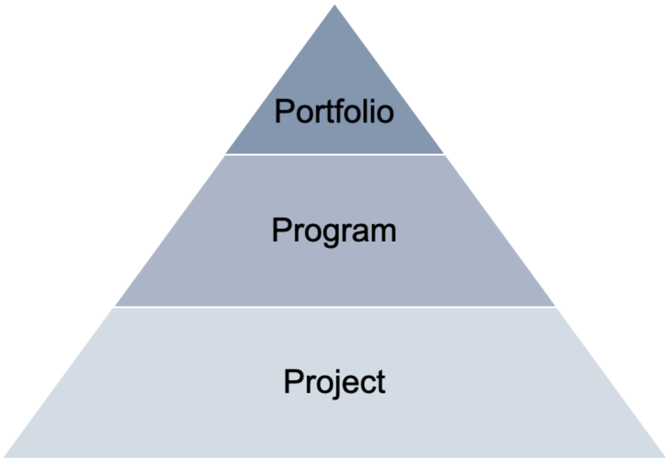

Figure 4.5 The relations between portfolio, program, and project.

The portfolio offers an overview of which projects and programs are currently run at RTD. It shows some key information about each, such as who is running it as well as who is the receiver.

There are currently five programs running or starting up at RTD, referred to as *The Big 5*. Each of these programs targets a specific market segment, e.g. Railway or Wind. These programs are a strategic initiative from the management of RTD, whose intention is to reduce the number of projects and instead focus the efforts on these segments. The goal is to utilize and synchronize the technology developed in the different projects, previously run independently, to faster reach the market.

The RTD project portfolio is available in a digital tool named Portfolio Project Management (PPM) in which, based on the information specified, each project receives a prioritization and the resources available at RTD can be allocated. The prioritization is made based on criteria that aim to ensure synchronization between the RTD projects and the strategic focus of the case company. This tool has been gradually implemented over the last two years.

4.2.2 **Product Development**

The PD department most often works with technology that has reached TRL 6 or higher. They are organized in two different teams. One team focuses on Application Specific Offers, which means they are making new variants of existing products to fit customers´ specific needs. The other team works with engineering: developing new products and versions of the product portfolio. The engineering team has a longer time horizon for their product development.

PD is the most common receiver of Material Innovations. Their responsibility is to incorporate the results of RTD´s work into products.

4.2.3 **Manufacturing & Process Development**

The MPD department identifies production-process needs and develops new and improved manufacturing processes for the factories. This takes place within TRL 3-8.

A critical process to ensure the quality of the bearings is the heat and steel treatment. This manufacturing process is closely connected to the Material Innovations, meaning there is a need for the RTD and MPD departments to work closely together.

4.2.4 **Product Line**

PL are responsible for presenting product strategies for the respective types of bearings as well as a plan for implementation of the strategy. The plan for implementation is known as *One Implementation Plan.* PL work with Material Innovations at TRL 1-9, meaning they have a strategic role in all stages of the Material Innovation process. Their involvement is, however, more critical once the Material Innovation reaches TRL 4 and becomes technology development rather than research, since it, at this stage, is clearer which product and market need the innovation addresses.

The department consists of people with experience from various parts of the case company, mostly from the PD and MPD departments. They are the link between the market and customer needs and the internal development departments. During the past year, there have been some organizational changes at PL.

PL has a strategic relationship with RTD. Meaning they act as the link to the customer and market needs, and shall give input to the RTD portfolio, ensuring the Material Innovations are demanded by the market.

4.3 Barriers

In this section, barriers observed at the case company causing the Material Innovations to not get past the TRL 6 interface, also known as *the valley of death*, are presented. At TRL 6, the technology development conducted at RTD shall be handed over. The most common receiver is PD but it can also, among others, be MPD. Moreover, the authors want to clarify that not all barriers occur in each departmental interface or project.

4.3.1 **Interface communication**

The empirical observations have been aggregated to three identified barriers: *not demanded technology, insufficient handover,* and *different resource prioritization.* These barriers, also referred to as second order themes, all contribute to one aggregated dimension, *interface communication.* This is visualized in Figure 4.6.

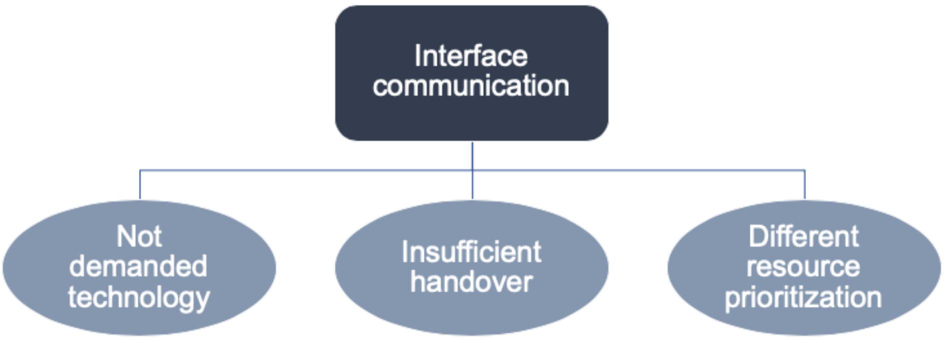

Figure 4.6 The umbrella problem as well as the three identified barriers.

Interface communication functions as an umbrella problem for the three challenges. The term interface refers to the interfaces between different departments and different stakeholders, as described in the process description in Section 4.1.1. It appears to be a lack of communication in these interfaces, which leads to the three barriers arising at TRL 6.

The barriers are further structured on a strategic, tactical, and operational level in Figure 4.7. These levels describe the time-horizon and perspectives of the observations. In Figure 4.7 it is further visualized which main barrier each observation links to. The three barriers and the related observations are discussed more in-depth in the following sections.

	Not demanded technology			Different resource prioritization		Insufficient handover		
Strategic (long-term)	Historically encouraged technology-push process	Incomprehension of the value of management perspective within RTD	Time gap between identification of market need and technology realization	Technology push from RTD, market pull from PD & PL	Unclear communication of how strategies are aligned			
Tactical (mid-term)	Different expectations between departments	Lack of guidelines and requirement specifications	Little/no follow-up after project start	Insufficient interdepartmental collaboration	Difficult to build a business case on a low TRL	Multiple receivers from RTD: difficult to define process of handover	Unclear ownership of requirements of technology development	Mismatch in competence between researcher and receiver
Operational (day-to-day)				Informal networks stronger than processes		Teams not cross-functional enough	Too short period for handover of projects	Technological communication: do not make complex technology understandable

Figure 4.7 Identified barriers that hinder technologies from getting past the TRL 6 interface.

4.3.1.1 Not demanded technology

A technology not being demanded when reaching TRL 6 refers to both internal and external demand. Externally it means that PL, that act as the link between the market and the company, experience that RTD do not deliver what is demanded by the market. Internally it refers to when RTD hands over the Material Innovation to, for instance, PD. Here, RTD sometimes experience that PD do not make use of what has been handed over. Hence, the technology delivered and developed is not demanded. The causes of this barrier appearing have been identified on the strategic and tactical levels.

Strategic

This problem appears to originate from the historical encouragement of a technology-push processes within the case company. The technology development has been done using the TRL scale since the mid 1990s when the model was first brought into the company. Since then and up to recently, researchers have been encouraged to drive a technology-push process, partly through the chosen Key Performance Indicators (KPIs). Examples of KPIs previously used are the number of reports published in the report archive and the number of filed patents. However, the case company now describes that they want their development and innovation to be based on a market pull.

Moreover, it seems as the insight of the value of a management perspective on which areas that should be focused on, is somewhat lacking within RTD. The researchers at RTD work with advanced technology and seem to perceive that the management is not initiated in their day-to-day activities. This leads to a challenge when it comes to aligning the research conducted with the long-term strategy and the market needs prioritized by management.

An effort to overcome this challenge was to introduce *The Big 5* programs described in Section 4.2.1.1. The efforts to implement these are ongoing as this thesis is being conducted. However, some initial challenges in communicating why these programs were chosen and why all research must be focused upon these segments have been observed.

Furthermore, the time horizon from initiation to finish of a Material Innovation can be several years. Hence, the customer needs and the company strategy can change during that time, making the innovation not demanded. The changes in the strategy and the market needs are not always communicated clearly along the projects and therefore projects are not stopped early enough.

Tactical

A difference in expectations on what role to take and what to deliver has been observed between the departments involved in the Material Innovation process PL are, by members of the RTD team, often seen as responsible for ensuring that the innovations developed are demanded by the market. PL, however, appears to consider their first mean of communication, when it comes to the need for new technology, to be the PD department. PD should thereafter communicate the needs to RTD, *"Product development should trigger research from RTD, not the opposite"*.

During an interview, a member of the RTD team stated that *"We don't know what they want, but that is not the way we want it to be"*, meaning RTD do not always know what PL and PD want them to deliver. The difference in expectations appears to be, partly, a result of a perceived lack of guidelines and requirement specifications on what deliverables should be met by the end of the technology-development phase. The guidelines and requirements must specify what demand to fulfill as well as what scope and limitations that should be met.

When there are set requirements or deliverables, an inadequate follow-up of these, between PD and RTD, is identified in some cases. An identified cause of this is that PD describe the relationship with RTD as a customer-supplier relationship, where RTD should work as a supplier to PD. However, again, the TRL scales that RTD uses fosters a technology-push process, which does not nurture this kind of relationship (Paun, 2012), making it challenging for the two departments to synchronize expectations and follow-up.

Furthermore, several technology projects are initiated by PL based on the identified market need. However, the follow-up from PL on how the initiated Material Innovations are developing over time comes across as inadequate. A lack of follow-up is an issue since there, as mentioned above, is a time gap between the identification of the market need and the technology realization. An interviewee stated that it is often presumed that *"no news are good news",* which could be a sign of the need of increased communication.

Not defining deliverables by the start of the technology development, and then updating the scope of the projects run, leads to development of internally not demanded technology. Furthermore, it is important to stop Material Innovations which there is no longer an identified external demand for.

4.3.1.2 Different resource prioritization

Different resource prioritization is a barrier that was lifted in numerous interviews. The perception is that technical development is often put on a shelf when approaching TRL 6 because the resource allocation between departments differs. This refers to RTD in relation to both PD, PL, and MPD. The barrier might take different forms in each interface. However, it results in an imbalance in all cases. The causes leading to *different resource prioritization* derive from the strategic, tactical, and operational levels.

Strategic

Firstly, the *different resource prioritization* appears to be a result of the mismatch of the push and pull processes. This is a problem since it leads to different focuses within the different departments and, hence, different resource allocation. RTD might prioritize different projects than PD, and PD might not prioritize the projects that RTD want to hand over.

Furthermore, the communication of how RTD's strategy (*The Big 5*) and PL's implementation strategy (*One Implementation Plan)* are aligned comes across as unclear, according to team members from both departments. The confusion seems to be rooted in the fact that *The Big 5* is not clearly communicated to PD and PL, and that *The Big 5* somewhat lack synchronization with *One Implementation Plan*.

Tactical

In the instances when RTD and PD have different priorities, it manifests as a difference in resource allocation. This appears to originate in a historical insufficiency in the interdepartmental collaboration. Again, relating to the communication between the departments. The observation of RTD, PD, and PL not having frequent enough communication to synchronize what should be prioritized seems to create this mismatch.

In addition, it is difficult to build a business case on a low level of the TRL scale and this is also a cause to the barrier of resource prioritization. Without a business case, a project will not be prioritized in a large organization, and resources will not be allocated.

Operational

Within the case company, informal networks are, to a large extent, stronger than formal processes. It has been mentioned that much of the work and communication are based on informal dialogues. These dialogs arise partly when people who previously have collaborated reach out to each other, and partly as people happen to be at the same place at the same time. When projects are heard of through informal channels, people seem to have a tendency of becoming biased. This can lead to resources and time being allocated based on incomplete information rather than the formal prioritization.

4.3.1.3 Insufficient handover

Insufficient handovers of technology development projects at TRL 6 have been mentioned as one of the main barriers in the innovation process. The causes of this barrier, appear to be on the tactical and the operational levels.

Tactical

One reason why insufficient handovers occur, is that RTD have different receivers of different projects, which makes it difficult to define one common process for the handover since different receivers have different needs.

Furthermore, a sense of unclear ownership of the requirements of a Material Innovation contributes to the insufficient handovers. The responsibility and accountability between involved departments and stakeholders do not appear to be clearly defined or well communicated. Thus, leading to difficulties in the handover as it results in a confusion of who is responsible for what at which stage of the process.

There also seems to exist a mismatch of competence between RTD and the receivers, due to different backgrounds and experiences. Hence, the level of technical competence as well as which language is spoken varies between departments, making the handover challenging.

Operational

The observation of teams not being cross-functional enough is mapped as yet a cause to the insufficient handovers. It appears as scarce collaboration at an early stage of a project leads to difficulties in the handover phase. Additionally, several of the interviewees perceive the handover phase as too short. This means that the receiver becomes involved in the project too late to be able to prepare for the handover and that RTD do not participate long enough after handing over the Material Innovation to transfer the implicit knowledge.

As previously mentioned, what appears to be a mismatch of competence between RTD and the receivers is another cause of the insufficient handovers. On an operational level, this is an issue, for instance, since RTD do not always succeed with their technical communication. Therefore, they seem to not accomplish to make complex technology understandable for someone who has not been involved in the project from an early stage. As mentioned previously, technical reports are written, however, these are often presented on a highly detailed level. Thus, it can be difficult to get a clear understanding of the technology when the report is the main source of information in the handover.

4.4 Best Practice

During the interviews conducted at the case company, examples of how to successfully overcome TRL 6, *the valley of death,* have been given. In this section, the common practices from these examples, combined with applicable literature findings, are presented in a framework.

4.4.1 **Successful implementation**

For an implementation to be successful, the challenges of the transfer at TRL 6 must be overcome. Having a clear scope and a clear commitment of resources from high-level management have been found to be central elements of ensuring success. The scope can be divided into two parts. The first one is that the problem which should be solved needs to be clearly defined. The other part is that any constraints to the solution presented, e.g. manufacturing processes or budget, also must be clearly stated from the start. The presence of these prerequisites seems to reduce the occurrence of the barriers previously presented.

As previously described, the barrier of *not demanded technology* refers to both internal and external demand. The external demand can be ensured by clearly defining what problem should be solved. A lack of internal demand can be addressed by having both a high-level management commitment and clearly defined constraints to the solution. A high-level management commitment should also ensure that the prioritization of resources for the technology developed is the same within all involved departments. Moreover, when the constraints to the solution are defined by the receiving department and fulfilled by RTD, a successful handover of a technology is enabled.

In order to increase the chances of getting both a well-defined scope and a commitment from management, several activities will now be presented. These activities are presented in relation to which barrier they aim to address in Figure 4.8-4.10, and thereafter again in the framework. A border in a different color than the bubble indicates that the activity addresses yet another barrier. All activities will be further developed upon in the following sections.

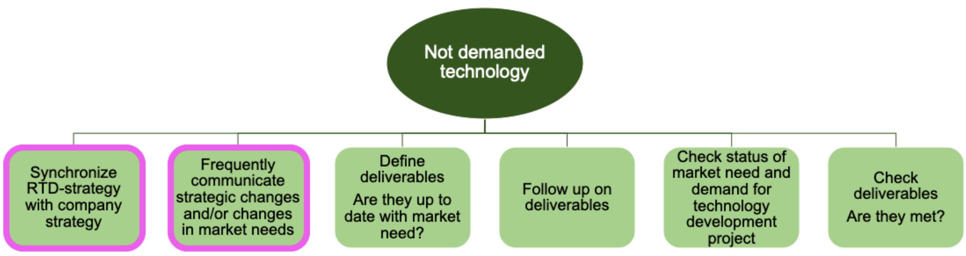

Figure 4.8 Best practice activities to address the not demanded technology barrier.

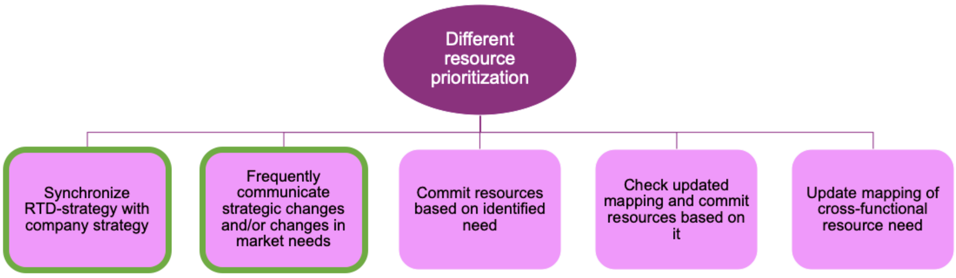

Figure 4.9 Best practice activities to address the different resource prioritization barrier.

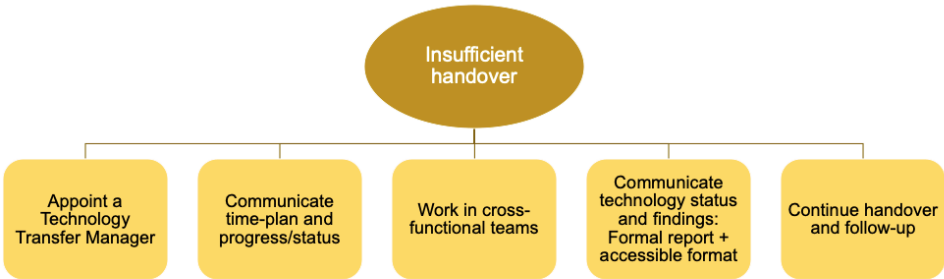

Figure 4.10 Best practice activities to address the insufficient handover barrier.

4.4.2 **Introducing the framework**

To further describe the activities presented above and how they relate to the existing Material Innovation process at RTD, a framework is introduced in Figure 4.11. It visualizes when the activities shall be performed in relation to the TRL scale in order to decrease the risk of the barriers appearing in the TRL 6 interface. Additionally, the previously introduced strategic, tactical, and operational levels are shown.[1]

Moreover, as in Figure 4.8-4.10, the green boxes indicate linkage to *not demanded technology,* pink to *different resource prioritization,* and yellow to *insufficient handover.* In the following sections, the activities will be further described and motivated.

[1] At a strategic level, the time-horizon of the decisions made is generally 2-5 years. On a tactical level, the time-horizon is 1-2 years and on an operational level it is day-to-day business.

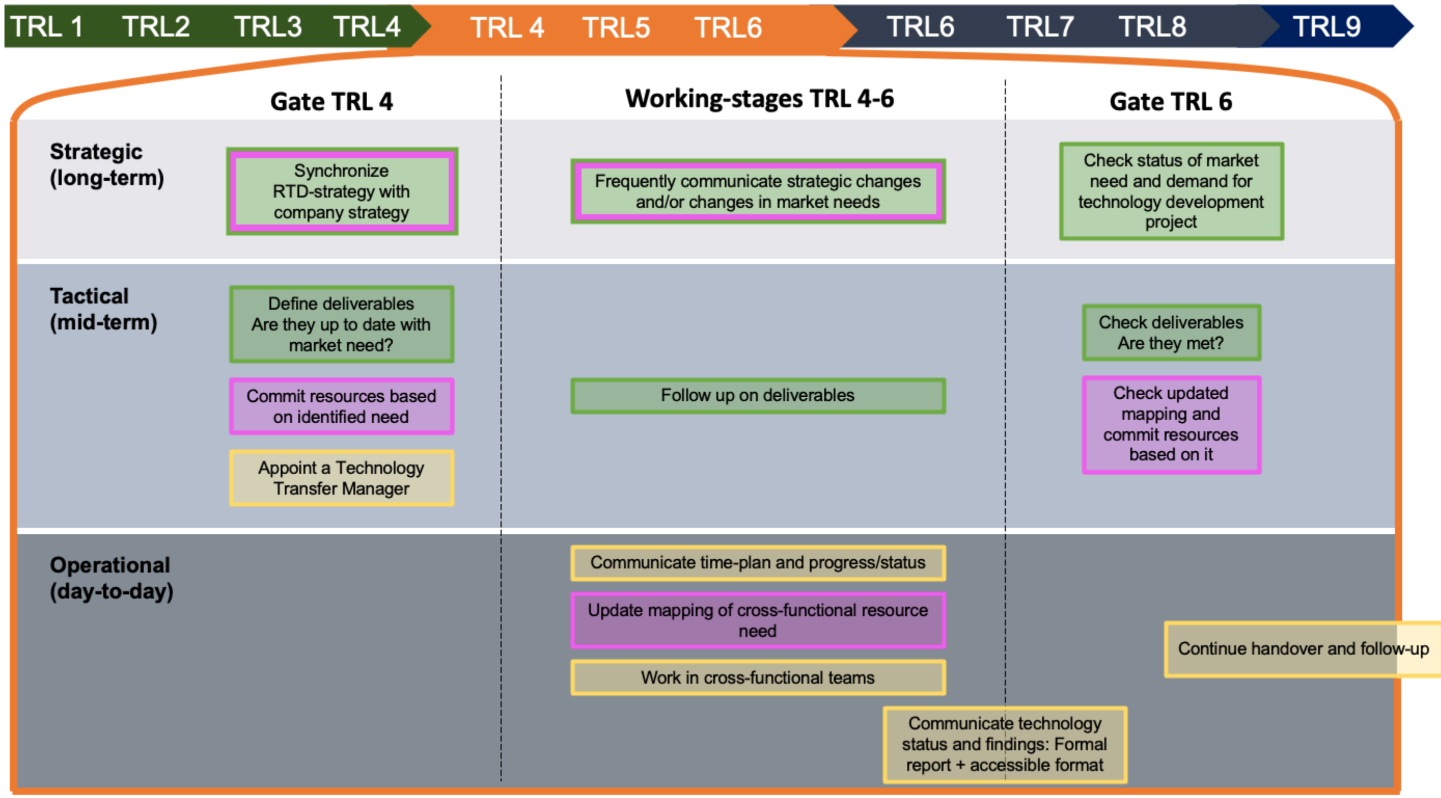

Figure 4.11 Ways of working in the range of TRL 4-6 to enable successful transfer of Material Innovations.

Gating

In the framework presented in Figure 4.11, two of the three phases are gates. Gating is not something new to the case company or RTD. However, it has been stated that the gates are not as effectful as they could be. To address this, best practice examples will be combined with elements of the SG process.

The key when gating is to ensure that it is not a *tooth-less* gate, meaning that to stop the development of a new technology is always an option, also in the later gates (Cooper, 2008). The gating activities presented in the following sections should be performed by the right level of management, meaning those who can ensure the commitment of resources and evaluate demand (Cooper, 1990), as well as the researchers involved. In summary, it appears to be essential to ensure that all identified stakeholders, including a customer representative (internal or external depending on the project), take part in the gating.

4.4.2.1 Gate TRL 4

Once the Material Innovation reaches the maturity of TRL 4, meaning it has proven some feasibility and is ready for further testing in a laboratory environment as well as in relevant environment, the technology shall pass through a gate. The goal at this stage of development is, according to Cooper (1990), to ensure that the project and further steps of development are clearly defined as well as that some level of attractiveness to the market exists.

It seems as, to enable a successful transfer at TRL 6, communication with management as well as interface departments regarding the specific Material Innovation, should take place regularly from now on. Up to TRL 4, the Material Innovation is still at an early stage and it is not certain if it will turn into a market offer. However, in the TRL 4 gate, it appears to be important to start establishing the communicational networks in order to prepare for a successful transfer in the case that the Material Innovation is proven feasible.

A summary of what need to be done in the TRL 4 gate and which questions must have a clear answer before passing the gate are described in Table 4.1. The activities will be further described in the following sections.

Table 4.1 Summary of what should be done in Gate TRL 4.

Perspective	*When?*	*What?*	*Questions to be answered*
Strategic	Gate	Synchronize RTD-strategy with company strategy	Is the Material Innovation in line with the company group strategy? Is it in line with One implementation plan?
Tactical	Before gate	Define deliverables	Which is the receiving organization? What must be proven to work before handing over to them? What requirements must be met in order to meet the identified strategic fit?
	Gate	Commit resources	Which departments need to be involved? How much and for how long?
	Gate	Appoint Technology Transfer Manager	Who should follow the Material Innovation from now to implementation?

Strategic

At a strategic level the key success factor for implementation, at this stage, seems to be securing alignment with the long-term strategy, *"you need projects that are demanded by product line and product development"*. Based on the observations, the most important part of this alignment is to ensure that the Material Innovation is within the scope of the current *One implementation plan*. By making sure that the Material Innovation is in line with this plan, it is also somewhat ensured that the company management believes that it is demanded by the market. Additionally, it enables an easier commitment of resources as the focuses are synchronized between the departments. Some efforts for this have already been made by RTD through prioritizing the projects in the portfolio partly based on a strategic-fit criterion. However, these efforts alone do not appear to be enough and a more intense dialog when gating is required.

Tactical

To ensure the alignment of the development with the company strategy, it is important to define what shall be delivered during the coming TRLs. This should be done in collaboration with the project manager, the receiving organization and other affected parties to incorporate the relevant aspects. The deliverables should then be clearly stated and agreed upon by all parties.

Clearly defined deliverables additionally enable a clear understanding of what resources are required. Moreover, it has been observed that it is vital that all involved departments commit these before the start of the development.

Another joint characteristic of the successful Material Innovations at the case company is that they have been run in the form of a program with an appointed Program Manager. The person in the role has been able to dedicate its time fully to synchronize the activities within the program. He or she has continuously communicated with management and other stakeholders to ensure that the program deliverables are up to date with any changes in the needs or scope. It has also been stated during an interview that it is important that "*you plan for post-delivery already at the beginning of the project*".

Not all technology development is large or complex enough to motivate a program. However, a *Technology Transfer Manager*, who shall follow the Material Innovation throughout its process, should always be appointed in order to enable the necessary synchronization, communication, and planning.

4.4.2.2 TRL 4-6

Once the technology development is up and running the most critical element, from the Material Innovation process point of view, appears to be to continuously communicate with all stakeholders.

The TRL scale is to be used in combination with a *technology maturation strategy.* The strategy should define the communicational and collaboration paths between the departments regarding the specific innovation (Héder, 2017). By ensuring that the questions presented in Table 4.2 are answered, the purpose of this strategy can be achieved.

In interviews with the case company, it has been stated that: *"people need to leave their own box"* and *"the unknown is known to someone else"*. This appears to be as important from a strategic perspective as from an operational. However, it occurs as it is not always clear how one should leave the box. Therefore, the framework presents activities, further described in Table 4.2 and in the following sections.

Table 4.2 Summary of what should be done in TRL 4-6.

Perspective	***When?***	***What?***	***Questions to be answered***
Strategic	Minimum every three months	Frequently communicate strategic changes and/or changes in market needs	Has the *One Implementation Plan* or *company strategy* been updated? Have we checked with the customer if their needs have changed?
Tactical	Minimum every three months	Follow up deliverables	Are the defined deliverables aligned with any identified changes in strategy, resources, or other?
Operational	Minimum every three months	Communicate time-plan and progress/status	Are there any deviations from the time-plan?
	Minimum every three months	Update mapping of cross-functional resource need	Has the resource need changed since the last update?
	Continuously	Work in cross-functional teams	Do we have representatives from relevant departments actively participating in our team?
	By the end of the phase	Communicate technology status and findings: Formal report + accessible format	Can someone outside of the technology development team understand what has been done?

Strategic

It appears as the barriers at TRL 6 can somewhat be overcome by communicating changes in market needs or strategy throughout the technology development. This should ensure that the developed technology will be demanded by the end of the Material Innovation process and that the resources are more easily synchronized between different departments.

Tactical

As the development of technology from TRL 4 to TRL 6 can last a few years it is important to follow up and update the defined deliverables as the work progresses. The view, in general, was that the main responsible party for this should be the receiving organization.

Operational

Nevertheless, the responsibility to keep the deliverables up to date does not only lie on a tactical level. On the operational level, it is important to communicate the progress and any changes in the time-plan. As the work progresses, it is also important to update any changed or new needs of resources.

Furthermore, the analysis of the best-practice cases showed that a cross-functional collaboration needs to take place. By involving the interested and affected parties, the sense of ownership and involvement in the development seem to spread.

When approaching TRL 6 and, thus, the end of technology development, it is time to document the work that has been done. To support the development team in the coming stages, it is important to have a technical report in place. Further, a more accessible format, such as a presentation, has been requested by the receiving parties. The accessible format could additionally address the possible mismatch of competence between the existing and the new team.

Moreover, it could enable identification of other possible applications than first intended for the Material Innovation developed. It appears as when the development has been done by a cross-functional team, the identification of other applications is more likely to happen organically. The knowledge of the findings is then already spread to the interested parties and they have understood the core of the findings.

4.4.2.3 Gate TRL 6

When reaching TRL 6, *the valley of death,* it is time to gate the Material Innovation again. After this gate, the technology is most often handed over from RTD to a different department. It has been observed that in addition to the previous efforts made up to this point, a successful technology transfer somewhat relies on the Technology Transfer Manager being active to ensure that the necessary tasks are conducted.

Moreover, at the TRL 6 gate, the previous stages shall be analyzed, and the gate should evaluate what to do in the coming stages, before the decision of whether to kill the project or run the next phase is made. According to Cooper (1990), after reaching this gate, the next stages of development will, in most cases, require heavier spending. Therefore, it is important to be more specific when defining the target market, product strategy, and positioning strategy (Cooper, 1990).

The coming steps are additionally characterized by development rather than research and the competence needed is therefore different. At NASA, the TRL levels are grouped with an intentional overlap to encourage a longer period of handover (Sadin et al., 1989). By prolonging the phase of handover in the framework, the interdepartmental gap at TRL 6 can somewhat be avoided.

There is a period of handover taking place at TRL 6 today. Possible ways of improving this are presented in Table 4.3 and further described in the following sections.

Table 4.3 Summary of what should be done in Gate TRL 6.

Perspective	***When?***	***What?***	***Questions to be answered***
Strategic	Gate	Check status of market need and demand for technology development project	Is a customer or segment identified for the Material Innovation?
Tactical	Gate	Check deliverables Are they met?	Has the Material Innovation been successfully tested in an applicable environment?
	Gate	Check updated mapping and commit resources based on it	How long handover phase do we need? Which resources should be committed?
Operational	After gating	Continue handover and follow-up	Has the knowledge been transferred?

Strategic

When gating at TRL 6 the main strategic responsibility has been found to be to check the synchronization of the Material Innovation with demand. As previously mentioned, the demand refers to internal as well as external demand for the developed Material Innovation. If either of these are not present, giving a go in the gate is not recommended.

In the case of not having a demand, it could be that the synchronization of the deliverables with strategy and market need has not been done frequently enough during development. However, that must not be the case. The material innovation process has a long timeline and, in some instances, outer circumstances change, making it the right decision to pause or stop the development at this stage.

Tactical

At a tactical level, the activities are also similar to the gate at TRL 4. However, since the TRL 6 is a milestone for a Material Innovation and the spending thereafter generally increases, a larger emphasis shall be put upon ensuring that the defined deliverables have been met. Furthermore, it appears as the resource allocation for the handover phase is sometimes inadequate. The common view at the case company was that it is important to commit resources from all involved departments for the coming months to avoid Material Innovations being put on a shelf at TRL 6.

Operational

From the cases observed it looks as though the Technology Transfer Manager plays an important role at this stage in the Material Innovation process. He or she shall in the gating enable the tactical and strategic decisions by providing the required information. Furthermore, it is important to ensure that the findings of the development are well documented. From a technical point of view, it is essential to provide a detailed report. As previously stated, a more accessible material has also been requested by the receiving departments.

As a part of reaching TRL 6 and passing the gate, the research usually transfers from RTD to PD, MPD, or another department. To ensure that knowledge and insight are transferred it appears to be of greatest importance that parts of the development team gradually hands over to the new team. The time frame of this is generally one to three months. However, it depends on the size of the project.

4.4.3 Combining DRL and TRL

It is important that the involved stakeholders in each stage of the Material Innovation process can understand each other when communicating. The responsibility lies not only on the researchers to explain the technology, but also on the people expressing the need. It must be clear what is demanded to be able to identify the required technical capabilities.

To integrate more of the market perspective into the Material Innovation process, the framework presented integrates elements of SG as well as recommendations from Klar et. al (2016) concerning adding perspective to the TRL scale. However, to further enhance the market-need perspective in the process and define how the needs should be described, the concept of DRL can be used. The matrix presented in Figure 4.13 is a generalization of the levels previously presented and visualizes the relation between the market pull and technology push.

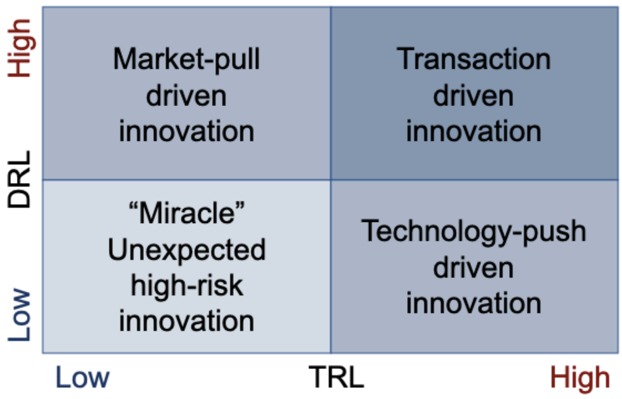

Figure 4.13 The matrix-wise relationship between TRL and DRL (Paun, 2012).

Hence, when the technical maturity of the Material Innovation has been defined, the market need should be expressed in accordance with the corresponding level of DRL. To reach the quadrant of *market-pull driven innovation,* which is the expressed goal at the case company, a low TRL must be complemented by a higher DRL, adding up to at least 11.

Thus, as the TRL increases, a lower DRL is required in order to match the technology development with a market need. For instance, when the maturity of the Material Innovation is TRL 4 a DRL 7 (*definition of necessary and sufficient competences and resources)* is required. Likewise, when the TRL is 6, a DRL 5 (i*dentification of systemic capabilities, including the project leadership)* is necessary (Paun, 2012). In the Material Innovation process, the input to TRL 1-4 is described as *knowledge needs* and to TRL 4-6 as *solution needs*. How to express these needs can be supported by the DRL scale.

5 Discussion

Why the Material Innovation process is not always successful and how the identified barriers can be addressed is further discussed in this chapter. One conclusion to bear in mind is that the TRL scale is a rooted part of the culture at the case company, hence the discussion is focused on identified ways of how to use the scale better. Additionally, the presented barriers and framework are further motivated.

5.1 Transferring Technology

When reaching TRL 6, the technology shall be transferred from a research stage to development. At a company, this often means transferring the technology between the R&D department and the Product Development department, thus risk to get stuck in *the valley of death*. Transferring technology from research to development is a complex stage of innovation (Nobelius, 2004). The reason behind initiating this thesis was that research is sometimes put on a shelf in the interface between RTD and PD at the case company.

The ITT research describes the challenges of communication in this interface and argues that the involved stakeholders speak different languages (Drejer, 2000). The same barrier has been identified at the case company. The challenges in communication, sometimes leading to different prioritization and lack of resources, are also barriers that have been identified in the case study.

Nobelius (2004) further elaborates that researchers and developers speaking the same language, thus communicating and working well together, as well as proven feasibility of the innovation, are two key success factors for the transfer of technology. Correspondingly, the purpose of the TRL scale is to define the technical maturity and feasibility of a technology. Hence, proven feasibility has not been identified as a barrier of transferring technology at the case company. Thus, it is concluded that the purpose of the TRL scale is fulfilled. However, the communication and interdepartmental collaboration are identified challenges and presented as the barrier *interface communication*.

This barrier was known to the people interviewed in the case study, however, the views on exactly what failed in the communication and how to address it did not appear to be aligned between the departments. What has further been identified is that the barriers causing challenges in the *interface communication* often relate to other stakeholders in addition to the RTD and the PD departments.

Furthermore, in a large company, no department acts in isolation of the company strategy or prioritization. Hence, efforts that are isolated only to the collaboration between these two departments will not be enough to overcome the barriers of technology transfer. Therefore, cross-functional collaboration and committed allocation of resources from all involved stakeholders are crucial elements of the presented framework.

The framework is inspired by the ITT framework found in Section 3.4.1, and offers clear guidelines on how to prepare for and deal with the TRL 6 interface. This framework starts at TRL 4, this is in line with the literature which states that the ITT should be treated as a continuous process and not only as a single action (Nobelius, 2004).

The guidelines are structured on the three levels *strategic, tactical,* and *operational* since this clearly highlights the need for commitment from and involvement of all levels of the company. Furthermore, by ensuring that the deliverables for the TRL 4-6 development are defined, agreed upon, and continuously updated, many of the observed problems at the case company should be avoided.

The framework aims to address the barriers which are not only found at the case company, but also in the ITT literature. It is therefore concluded that the framework could be of general interest to industrial companies using the TRL scale in order to avoid *the valley of death*.

5.2 Challenges of the TRL Scale

The TRL scale is not a process itself. It comprises of nine definitions of how to describe and enable discussions concerning the research conducted at NASA, as presented in the original paper published by the same institution in 1989. (Sadin, Povinelli, & Rosen, 1989) At the case company, the TRL scale has become crucial when defining the Material Innovation process.

Klar et al. (2016) conducted a study at a company in the iron and steel industry, which also works with the TRL scale to define their research projects. The authors identified that when using TRL for assessing technology development, the scale is missing several elements. Two examples of these are consequential changes in the manufacturing processes and explicit management involvement (Klar et al., 2016).

When using the TRL scale for the Horizon 2020 framework, Héder (2017) highlights the problems concerning the fact that TRL fosters a technology push process in the presented format. Meaning, many aspects of what the market and endusers need from the research might be disregarded. The same barrier has been identified at the case company.

With TRL nurturing a technology push process, the market needs are often not clearly incorporated when setting the deliverables for the next phase of development. Recognizing that TRL is a scale that encourages a technology-push behavior is an important step towards understanding and addressing the barriers found at the case company.

The scale´s ability to stick around for so long despite its weaknesses could be explained by the fact that it builds on the Linear Model of Innovation which has been used for almost a century (Godin, 2006). The Linear Model is rarely representative of how the innovation development takes place. However, since the model enables simple classifications of research and development, and thus allocation of resources, itself, and by extension the TRL scale, are popular amongst management.

At the case company, the lack of market orientation and the missing dimension of clear management commitment in the TRL scale contributes to the barriers appearing at the TRL 6 interface. These challenges with the scale are to be expected at other companies as well.

5.3 Taking the TRL Scale One Step Further

The successful cases presented at the case company all have one thing in common: they have added elements to complement the use of TRL throughout the technology development. These elements have all together resulted in more frequent communication with involved stakeholders, building a bridge over the TRL 6 *valley of death*.

Although all barriers identified concern the transfer of technology, the causes of them appearing can be traced back to the earlier stages of the Material Innovation process. In the ITT literature, the emphasis is put on securing scope and resources to enable a successful transfer (Nobelius, 2004). The very same actions are described in the background as to why the SG process is presented. Furthermore, SG focuses on pre-development and that the technology developed should have a clear market orientation (Cooper, 1990).

Gating of projects, which is the core of the SG process, has already been implemented for larger projects at RTD. In the best practice cases presented in interviews, technology development projects are gated at TRL 6. This implies that combining TRL with elements of the SG process results in a well-functioning Material Innovation process at the case company. Therefore, the framework introduces two gates during the technology development phase, thereby combing SG with the TRL scale.

However, the challenge is to make gating easier for the smaller Material Innovations which do not have a large program or project organization that support them. By introducing the framework that describes when, how, and which level of the organization needs to be involved, this should be enabled. The authors of this thesis however want to emphasize that the research shall sometimes be stopped at a gate, and that is not the same as research being put on a shelf due to barriers appearing.

Furthermore, by appointing a Technology Transfer Manager for all Material Innovations, the synchronization of activities over the lifetime of the innovation are to be improved. Additionally, by stating which questions need to be addressed at each stage of TRL 4-6, including at the gates, the deliverables and the commitment is to be easier obtained. When defining the questions to be answered, the authors were inspired by Klar et al. (2016), who defined questions as a response to the lack of management involvement. The questions presented in the framework incorporate the needs identified at the case company.

The original presentation of the TRL scale addresses the gaps between the levels by having an international overlap of the TRLs between the different development teams. This is incorporated into the framework by lengthening the handover phase and by strengthening the cross-functional collaboration.

Moreover, how to communicate the market needs, in relation to achieved TRL, is challenging. Therefore, the DRL scale is introduced as a mean to complement the framework. The purpose of the DRL scale is to offer clear guidelines on how to express the demand in relation to where the technology is at the TRL scale (Paun, 2012). The barriers observed at the case company are the same as the problems aimed to be addressed by the DRL scale.

In conclusion, by combining the definitions of the TRL scale with gating as the SG process suggests and defining activities to ensure scope and resource commitment as stressed by the ITT literature, the challenges of the TRL scale are to be overcome.

6 Conclusion

In this chapter, the academic contribution of the thesis is described and suggestions for future research are given. Lastly, the implications of the thesis' results for industrial companies working with TRL are elaborated on.

6.1 Academic Contribution

In conclusion, the TRL scale is a renowned and used tool for defining the maturity of a technology development. It originates in the Linear Model of Innovation and thus enables clear classifications of innovation, which makes it an attractive tool for companies to use. Defining innovations on a scale also offers support to allocate resources to different types of research, and it appears as the TRL scale is here to stay.

However, it has been found that the TRL scale not being a process itself has caused challenges in the Horizon 2020 framework, for companies in the steel process industry as well as at the case company. Barriers in the Material Innovation process have been identified and they are in line with the common challenges described in the ITT literature.

In the original paper about TRL, strategies are presented to address how to best work with the scale in order to avoid the gaps within it. These strategies are, together with elements from the SG process and ITT key success factors, incorporated into the framework presented in this thesis. To further enhance the use of the TRL scale, it is recommended to use the DRL scale in combination with TRL to better communicate the market needs. Thus, the purpose of this thesis is served.

6.2 Future Research

An issue that has been brought up which further makes the Material Innovation process challenging is reorganization. This puts additional stress on the process, both when these take place within the research team, as well as within the stakeholders, management, or receiving department. However, the issue of reorganization during the lifetime of developing an innovation is not something found in the literature reviewed. Why companies reorganize themselves and how to best approach this is although well researched. Combining this knowledge with the ITT literature as well as the SG process could be a future contribution to the research field of innovation.

Furthermore, the research on the effects of using DRL is scarce. To confirm the recommendations of Paun (2011), a study on whether or not the use of the DRL scale in combination with the TRL scale does improve the communication between R&D and the applications of the research are suggested as future research.

6.3 Implications for Industrial Companies Working with TRL

For the case company, it is recommended that the framework is implemented with support of the PPM tool. The tool can be used, for instance, to visualize information and support discussions about resource allocation and prioritization. It can also facilitate the alignment of strategies by the overview of projects it offers.

Furthermore, the presented framework addresses barriers that are commonly found in literature on innovation processes and ITT. It further aims to address the use of the TRL scale on a standalone basis and the fact that it is not a process itself, by incorporating elements of the SG process and ITT success factors. Moreover, by enhancing interdepartmental collaboration and communication, it should contribute to reaching a balance between technology push processes nurtured by TRL and the aspiration of developing innovations based on market pull.

Thus, the framework is not only relevant for the case company, but for industrial manufacturing companies using the TRL scale in general. Implementing the framework, should lead companies on the right path towards more successful development efforts and overcoming the challenges connected to the technology transfer at TRL 6, *the valley of death*.

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Appendix A Interview Guide

Background questions

What is your role?

- What are your areas of responsibility?
- What tasks does the role include?

How long have you been working at the company?

- What did you do before you got your current role?

Main questions

Technology readiness levels

Are you familiar with the TRL-scale?

Have you been working with TRL?

- What level of TRL do you believe you work with?
- What level of TRL does your department believe it works with?
- How does the work with TRL function from your perspective?

How do your interfaces with other departments look related to TRL?

- How and wherefrom do you get input of when you should begin your part of the work with TRL?
- How do you handover when you are "done" with your part of TRL?
    - To whom?
- What communication channels do you use?

Theoretical processes

Do you perceive that you have insight in what kind of projects are currently running?

Do you perceive that your department have insight in what kind of projects are currently running within RTD?

- How do you get information about current development projects? (If you get information.)
- How does information spread?

Do you have established processes for how you should work with development (in addition to TRL)?

- Have you been working in different ways before?
    - How is your current approach in relation to your previous ways of working?

Is it something you think you could improve or do different?

- Is it something that you think is challenging?
- Do you have any suggestions of how you could be working instead?

Projects in practice

Can you give an example of a development project that was successful?

- How did that project move along the TRL scale?
    - What stakeholders were involved?
- How did the resource allocation work?

Can you give an example of a development project that was less successful?

- How did that project move along the TRL scale?
    - What stakeholders were involved?
- How did the resource allocation work?

Appendix B List of Interviewees

Table B.1 List of interviews conducted.

Department	***Date***	***Type of interview***
RTD	22/1-20	In person
PD	23/1-20	In person
Other	23/1-20	In person
Other	24/1-20	In person
RTD	23/1-20	In person
PD	24/1-20	In person
Other	13/2-20	Video call
RTD	20/2-20	Video call
PL	26/2-20	In person
RTD	27/2-20	In person
RTD	27/2-20	Video call
RTD	27/2-20	In person
Other	27/2-20	In person
MPD	28/2-20	In person
RTD	28/2-20	In person
Other	28/2-20	In person
PL	2/3-20	Video call
RTD	2/3-20	Video call
PD	2/3-20	Video call
RTD	19/3-20	Video call
RTD	19/3-20	Video call
RTD	19/3-20	Video call
RTD	20/3-20	Video call
RTD	20/3-20	Video call
MPD	24/3-20	Video call

When it is stated that department is *Other*, it means that the interviewee is employed in a department that is involved in the Material Innovation process but is not the focus of this thesis or have previously been employed in one of the departments involved.

Appendix C Synthesized Analysis of Empirical Observations

In Table C.1, both empirical observations and identified barriers are described. In column one, the empirically observed barriers are stated. To visualize how frequently the different barriers have been mentioned they have been color-coded on a scale from 1-5. The brightest meaning less frequent and darkest meaning more frequent.

Further, column two contains three identified problems that have been mentioned repeatedly in the interviews conducted. These have been further strengthened through the authors' analysis and grouping of the empirical observations in column one. Lastly, column three discloses an aggregated dimension that works as an umbrella problem for the barriers in column two.

Table C.1 Identified barriers.

1st order concepts	*2nd order themes*	*Aggregated dimension*
Historically encouraged technology-push process	Not demanded technology	Interface communication
Incomprehension of the value of management perspective within RTD		
Time gap between identification of market need and technology realization		
Different expectations between departments		
Lack of guidelines and requirement specifications		
Little/no follow-up after project start		
Technology push from RTD, market pull from PD & PL	Different resource prioritization	
Unclear communication of how strategies are aligned		
Insufficient interdepartmental collaboration		
Difficult to build a business case on a low TRL		
Informal networks stronger than processes		
Multiple receivers from RTD: difficult to define process of handover	Insufficient handover	
Unclear ownership of requirements of technology development		
Mismatch in competence between researcher and receiver		
Not enough cross-functional teams		
Too short period for handover of projects		
Technological communication: do not make complex technology understandable		

Appendix D Horizon 2020 Definitions of TRL

Table D.1 TRL adapted to Horizon 2020 (Mankins, 1995; European Commission, 2019).

TRL	***NASA Definition***	***Horizon 2020***
1	Basic principles observed and reported	Basic principles observed
2	Technology concept and/or application formulated	Technology concept formulated
3	Analytical and experimental critical function and/or characteristic proof-of concept	Experimental proof of concept
4	Component and/or breadboard validation in laboratory environment	Technology validated in lab
5	Component and/or breadboard validation in relevant environment	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in a space environment	System prototype demonstration in operational environment
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)	System complete and qualified
9	Actual system "flight proven" through successful mission operations	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Appendix E Work Distribution and Time Plan

In this appendix, it is presented how the work has been distributed among the authors, followed by the time plan for the thesis and the outcome of performed activities.

E.1 Work Distribution

Both authors have participated in all activities performed during the thesis. The authors have been working at the same place and continuously discussed the tasks that have been carried out. This have resulted in a 50/50-distribution of the work and all sections have been written in collaboration. It is, therefore, not possible to state exactly what have been done by each author.

E.2 Time Plan and Outcome

In Figure D.1 the time plan for the thesis can be viewed. The phases in the time plan correspond to the phases described in Section 2.1: *Discover, Define, Develop*, and *Deliver*. In addition to these phases, the time plan includes *Thesis start* and *Outcome.* It is described very short in the figure what the focus within each phase was.

The periods to the right in the time plan lasted one week each and period 1 starts the 20^{th} January. The colors in the time plan are described in the figure. Moreover, the date in parentheses following each phase´s name is the planned start-date for the phase.

Some differences between the time plan and actual duration of the phases have occurred, as can be seen to the right in the figure. The *Thesis start* lasted one week longer than planned due to more meetings and practical matters to handle during the first visit at the case company than expected.

Furthermore, the mapping of the problem was more time consuming than expected. Therefore, the *Discovery* phase lasted one week longer than planned as well. Hence, the phase of *Defining* was entered two weeks after planned start. It, however, lasted for five weeks as planned. Thus, the *Develop* phase also begun two weeks later than planned. This phase was shortened by two weeks, since much of the work planned, e.g. literature searching, for this phase had already been carried out during the earlier phases.

Because of the shortened *Develop* phase, the phase of *Delivery* was entered at planned start. It lasted during the planned four weeks. Moreover, the phase *Outcome* was started as planned and the duration did not deviate from the time plan.

Time plan

ACTIVITY	PLANNED START	PLANNED DURATION	ACTUAL START	ACTUAL DURATION	COMPLETED PERCENTAGE
Thesis start - Explore problem background (20/1)	1	1	1	2	100%
1. Discover (27/1) - Mapping	2	3	3	4	100%
2. Define (17/2) - Process data	5	5	7	5	100%
3. Develop (23/3) - Identify ways to adress problem	10	5	12	3	100%
4. Deliver (27/4) - Compile results and write report	15	4	15	4	100%
Outcome (25/5) - Presentaion & opposition	19	2	19	2	100%

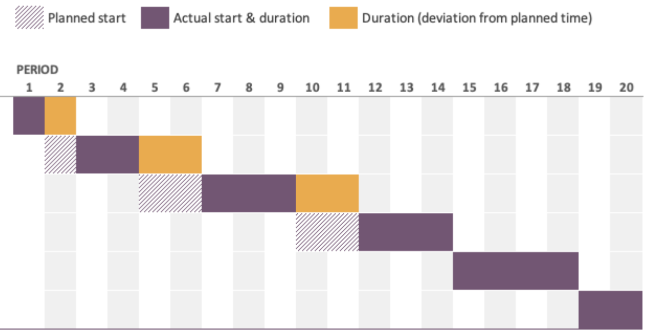

Figure E.1 Planned and performed activities.