UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Master Degree Project in Innovation and Industrial Management

Technology Roadmapping for Manufacturing

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Abstract

Technology roadmap has emerged as a popular tool for technology development during the last couple of decades. It enables the organization to ask itself questions regarding the gap between the current and future state to identify and assess technology alternatives. The research project's focus lies on the process behind the creation of technology roadmaps, which is called technology roadmapping. The absolute majority of existing literature overlooks the concept's application to manufacturing development, meaning that there is a need to investigate this topic further.

This research project takes into consideration a case organization, which is currently developing and implementing technology roadmapping as a core tool to prepare manufacturing for the future. The empirical material for the research project originates from the case organization, a benchmark study with both internal departments and external companies, and a consultation with an expert within manufacturing development.

The results of the research project indicate that the generic technology roadmapping process available in existing literature is, given some customization of critical factors, applicable to manufacturing development. The theoretical implication of the research project is mainly a contribution to existing literature regarding technology roadmap's application to manufacturing development. The practical implication is that any manufacturing company wishing to introduce technology roadmap in its organization can use the result of this research project as a guide to set up the fundamentals for the technology roadmapping process.

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List of Abbreviations

TRL	Technology Readiness Level
MRL	Manufacturing Readiness Level
MPA	Modular Production Architectures

List of Definitions

Technology Roadmap	"*Roadmaps provide an extended look at the future of a chosen field of inquiry drawn from the collective knowledge and imagination of the groups and individuals driving change in that field*" (Galvin, 2004, pp. 101)
Technology Roadmapping	"*Roadmapping is the activity of creating and then communicating the roadmap*" (Kappel, 2001, pp. 41)

1 Introduction

The following sections present an introduction of a research project in Innovation and Industrial Management at the School of Business, Economics, and Law at the University of Gothenburg. The research project puts attention to the concept of technology roadmaps and its application to manufacturing development. The first two sections provide a background to the concept and a motivation to the relevance of the research project. The final section of the introduction presents a description of the research project's purpose, research question, delimitations, and disposition.

1.1 Background to the Roadmap Concept

The globalization trend is a major challenge for companies competing for survival in the fierce business climate of today. Globalization of markets, suppliers, and competitors in combination with increasing customer demands puts high pressure on existing companies to stay competitive on the global business arena. One of the most important factors to create competitive advantage is to develop or acquire technologies needed to manufacture innovative products (Gindy, Cerit, & Hodgson, 2006). In addition, shorter product life cycles and intensified customer demand for customization are two examples of challenges companies face today (Gerdsri, Vatananan, & Dansamasatid, 2009; Menck, Weidig, & Aurich, 2014). Shorter product life cycles also put pressure on manufacturing technologies to match the new products. These trends imply a strengthened focus on technology development to stay competitive (Nyhuis, Wulf, Klemke, & Hirsch, 2010). Hence, it is vital to ensure alignment of technological capabilities and market needs, both today and in the future (Phaal, Farrukh, & Probert, 2004; Lee, Phaal, & Lee, 2011).

In the 1970s, Motorola identified the need to support the relation between technology plans and strategic products, which resulted in the emergence of the roadmap concept. A roadmap is a concept companies can use to handle future challenges, as it enhances technology development through the alignment of strategy and innovation (Phaal, Farrukh, & Probert, 2005; Phaal, Farrukh, & Probert, 2004; Simonse, Hultink & Buijs, 2014; Lee, Phaal & Lee, 2011; Gerdsri, Vatananan, & Dansamasatid, 2009).

Daim and Oliver (2008) describe roadmap as a method to identify and decide upon trajectories to follow to reach future success, similarly as a traditional map guides travelers to their destination. A roadmap is, according to Phaal, Farrukh, and Probert (2005), not definitive as it can take on various forms. However, the underlying fundamentals usually relate to three specific features, as it provides the company with an illustration over the current state, a desirable future state, and strategies to reach the future state (Phaal, Farrukh, & Probert, 2005).

The most common term of the roadmap concept is technology roadmap, yet there is no absolute definition of the concept (Lee & Park, 2005). Technology is only one aspect of technology roadmap and several other factors are in reality also included (Lee & Park, 2005; Phaal, Farrukh, & Probert, 2005). The concept also takes areas such as innovation, business, and strategy into consideration (Lee & Park, 2005; Phaal, Farrukh & Probert, 2004). Rinne

(2004) illuminates how technology roadmaps have become a popular tool to handle the next generation of technologies. Technology roadmap facilitates both identification of potential technologies and creation of action plans for technology development and implementation. This report uses the terms technology roadmap and roadmap interchangeably.

Research on technology roadmap gained momentum in the 1990s and has grown to be a popular concept in both business and academia. For instance, a survey presented in the article by Vishnevskiy, Karasev, and Meissner (2015) appreciates that ten percent of all manufacturing companies use technology roadmap. A search on technology roadmap generates 1116 articles[1] and *figure 1* shows their distribution over time. Researchers paid much attention to technology roadmap in the last years of the 1990s and the concept had its peak in terms of publications in 2007, while the yearly average has decreased slightly in subsequent years.

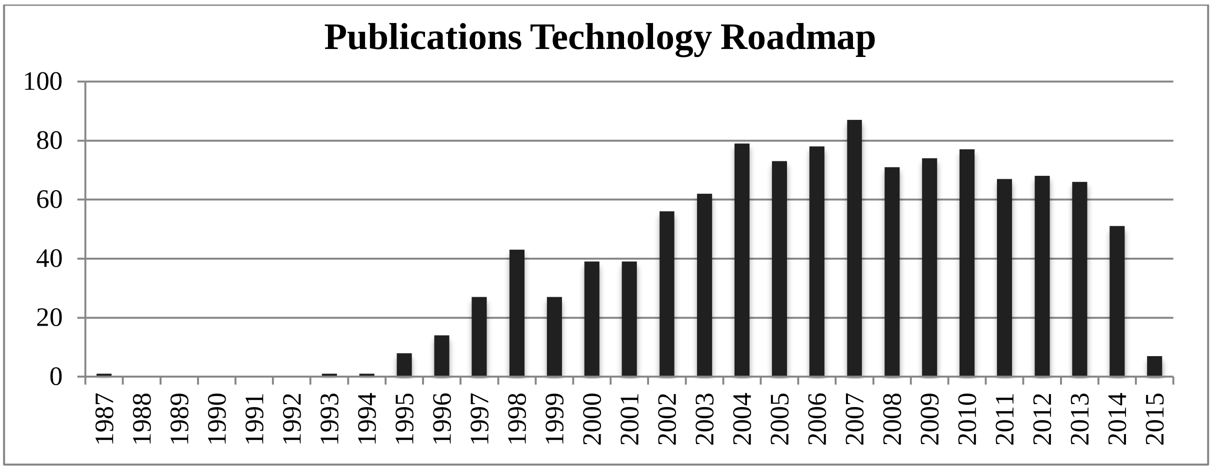

Figure 1. Articles generated on the search term "Technology Roadmap" at Web of Science

1.2 Motive for the Research Project

Phaal, Farrukh, and Probert (2005) imply that technology roadmaps often emerge separated from each other in organizations. Departments tend to use roadmaps in different ways and there is often no universal solution. Lee and Park (2005) mention that different roadmaps usually relate to their respective purposes. Existing literature frequently focuses on general roadmaps and neglects customization, which make it difficult for companies to implement these general roadmaps in practice (Lee & Park, 2005; Lee, Phaal & Lee, 2011).

Nyhuis et al. (2010) imply that companies often experience a missing link between strategic and operational plans. Companies tend to put effort on product development and associated technologies, while paying less attention to manufacturing technologies. Vielhaber and Stoffels (2014) add that the scientific coverage of manufacturing development is relatively low in comparison to product development. Yet, the relationship between a product's material and manufacturing technologies is vital to consider in an early stage of the development process. The choice of material for a new product is often made before the consideration of

[1] Search on topic ”Technology Roadmap” at Web of Science 2015-04-29

manufacturing technology. The lack of coordination between product and manufacturing development often results in large investments in new machines, which leads to complex manufacturing processes. One of the main reasons for the missing link is the absence of a systematic and standardized tool to ease coordination of strategic and operational activities (Nyhuis, et al., 2010). Kappel (2001) found that there is a need to standardize the roadmapping process throughout the organization, thus similar formats and routines enable coordination across functional borders.

1.3 Purpose

Existing literature tends to focus on general technology roadmapping processes and neglects their application to manufacturing development. Hence, there is a need to investigate factors important for manufacturing to create a roadmapping process applicable within manufacturing development. The purpose with this research project is to develop a technology roadmapping process, which companies can use as a framework for manufacturing development.

1.4 Research Questions

The main research question relates to the overall purpose of the research project and focuses on technology roadmapping for manufacturing. Three research sub-questions identify necessary building blocks for the technology roadmapping process and contribute to the answer of the main research question.

Main research question: How can Technology Roadmapping be applied to manufacturing development?

Sub-question 1: What is Technology Roadmap?

Sub-question 2: What is Technology Roadmapping?

Sub-question 3: Which factors related to manufacturing need to be considered in Technology Roadmapping?

1.5 Delimitations

The focus in this report lies on technology roadmapping for manufacturing. The researchers do not put any effort to the prediction of future technologies or the roadmap's company specific content. It is the methodology behind the creation of technology roadmaps that is of interest in this research project.

Another delimitation relates to the scope of the technology roadmapping process, thus the focus is the methodology behind the development of the roadmap content. Organizational preparation and introduction of the concept fall outside the scope of this research project. The reason for this is that such activities are similar to other change management theories and not specifically related to the theories of technology roadmap.

1.6 Disposition of the Research Project

Figure 2 provides the disposition of the research project, which is a structure for how to find the answer for the main research question. The introduction presents a background to technology roadmap and a motivation for the research project. The purpose and research questions end the introduction section. The literature review and empirical material collection aim at jointly fulfilling the purpose. Both the literature review and the empirical material provide inputs to all research sub-questions. The analysis section presents a comparison of theory and practice based on the results from the literature review and empirical material. The conclusion presents the eventual result of the research project, which is a technology roadmapping process for manufacturing development.

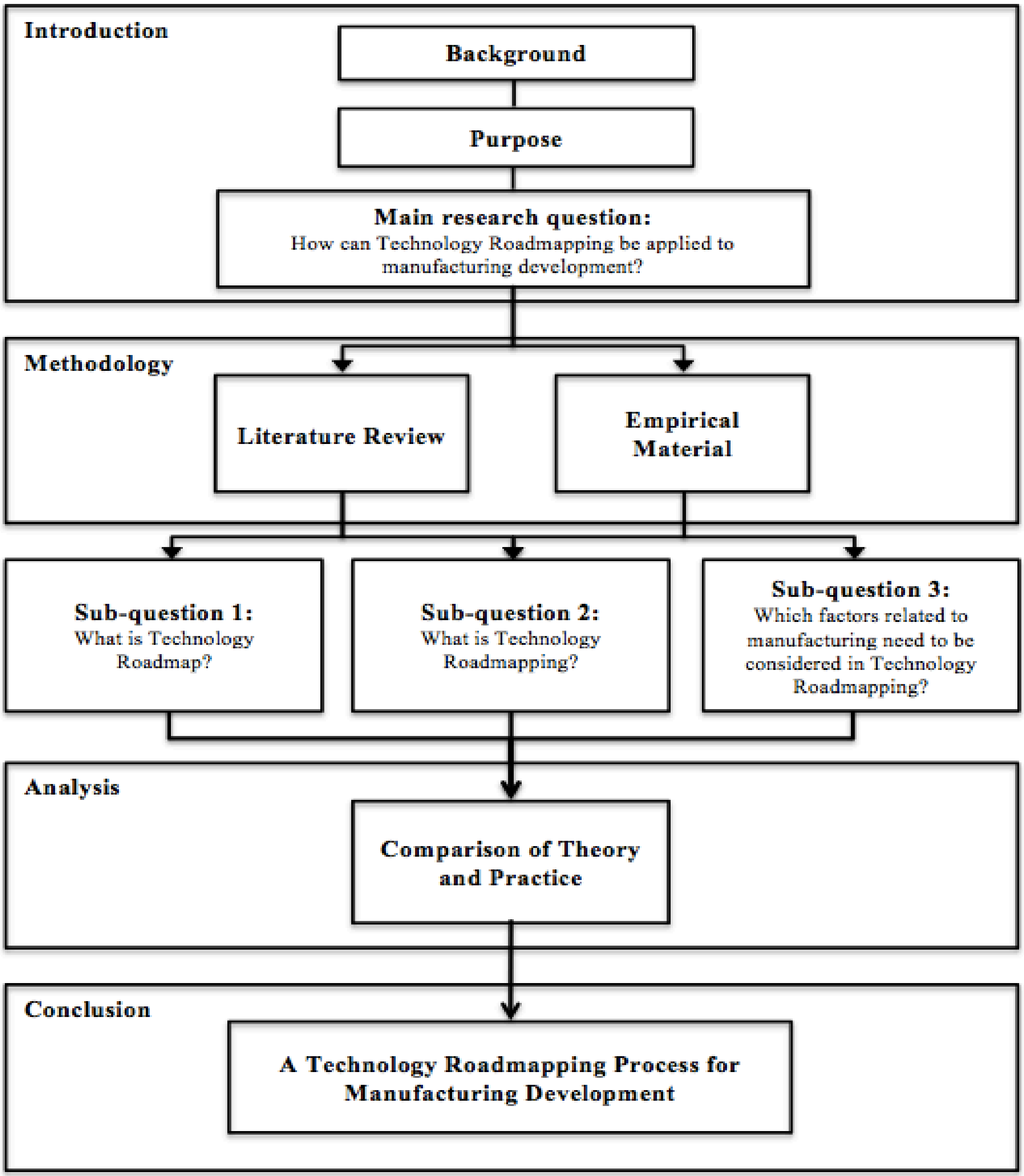

Figure 2. Report Disposition

2 Method

The method for the research project is the focus of subsequent sections. The epistemological and ontological positions, the research strategy, the research design, and the methods behind the literature review and empirical findings are the major issues dealt with below.

2.1 Epistemological and Ontological Positions

For the reason that this research project takes an organization and its individuals into consideration, it is a study within social sciences rather than natural sciences. Therefore, the epistemological position is in line with the principles of interpretivism because the characteristics of the research require the researchers to interpret empirical material gathered during the process. Bryman and Bell (2011) argue interpretivism is suitable for studies in social sciences that require a certain degree of subjective interpretation.

The research project follows a constructivist perspective in terms of its ontological position. The behaviors of social actors play a significant role and their opinions and experiences are vital inputs to the research project. The assumption is that the environment is in constant change and depends upon the social actors within it, which is why a constructivist perspective is appropriate (Bryman & Bell, 2011).

2.2 Research Strategy

This research project focuses on how companies can approach the concept of technology roadmaps for manufacturing development. A qualitative research strategy is a suitable choice because it lets the researchers explore issues in depth, thus it emphasizes the inclusion of words rather than numbers (Bryman & Bell, 2011).

A qualitative strategy most often relates to an inductive approach for the relationship between theory and research. The basic notion behind an inductive approach is to generate new theory, which has its base in both existing theories and empirical findings (Bryman & Bell, 2011). The opportunity to combine existing theories and empirical findings from a case company and other benchmark companies creates a strong foundation for the development of new theory on the subject of technology roadmaps for manufacturing development

2.3 Research Design

Bryman and Bell (2011) describe that case studies has the characteristic to find detailed information about a specific phenomenon. Case studies are applicable for the analysis of, for instance, a single organization, a single location, a person, or a single event. In this research project, the researchers use the case study design to analyze a single organization in general and how a department works with a specific activity in particular. The difference between a case study and other types of research design methods is that it focuses on a delimited system or situation. Bryman and Bell (2011) illuminate how the case study design often relates to the qualitative research strategy. Further, Bryman and Bell (2011) advocate the reasoning behind pursuing with case studies is to maximize learning. This argument strengthens the choice of conducting a case study, thus the focus of the research project is to develop a technology roadmapping process for manufacturing development with emphasis on learning and continuity.

This research project focuses on a case study of the technology department at a multinational manufacturing company (department AA), which during the year of 2014 introduced technology roadmap as a major building block in the development of manufacturing processes. The individuals working at the department have practical experience related to manufacturing and are now outlining the overall process behind technology roadmap. The process for generating technology roadmaps should be used globally as a standardized tool for manufacturing development. Therefore, the assignment of this research project is to support the establishment of a technology roadmapping process through the analysis of existing literature and empirical data from department AA, a benchmark study, and consultation with an expert within manufacturing development.

The concept of grounded theory forms the basis of the research design and the research question is the starting point for this research project. The next step in the process is to review existing literature and form theories, which functions as a base for the upcoming analysis. Codification and categorization of existing theories enable comparison of different models and concepts. The empirical material collection provides additional primary data, which the analysis then compares with the literature review (Bryman & Bell, 2011).

To close the gap in existing literature, three fundamental building blocks are required. First, a generic literature based technology roadmapping process that is not specifically tailored to manufacturing development. Second, practical technology roadmapping experiences collected through a benchmark study including two external companies (B & C) and two internal departments (AB & AC). Third, general experiences and opinions related to manufacturing processes provide additional factors to include in the new technology roadmapping process. Internal interviews with respondents at department AA and an industry expert within manufacturing development at company D provide these inputs. *Figure 3* depicts the three building blocks.

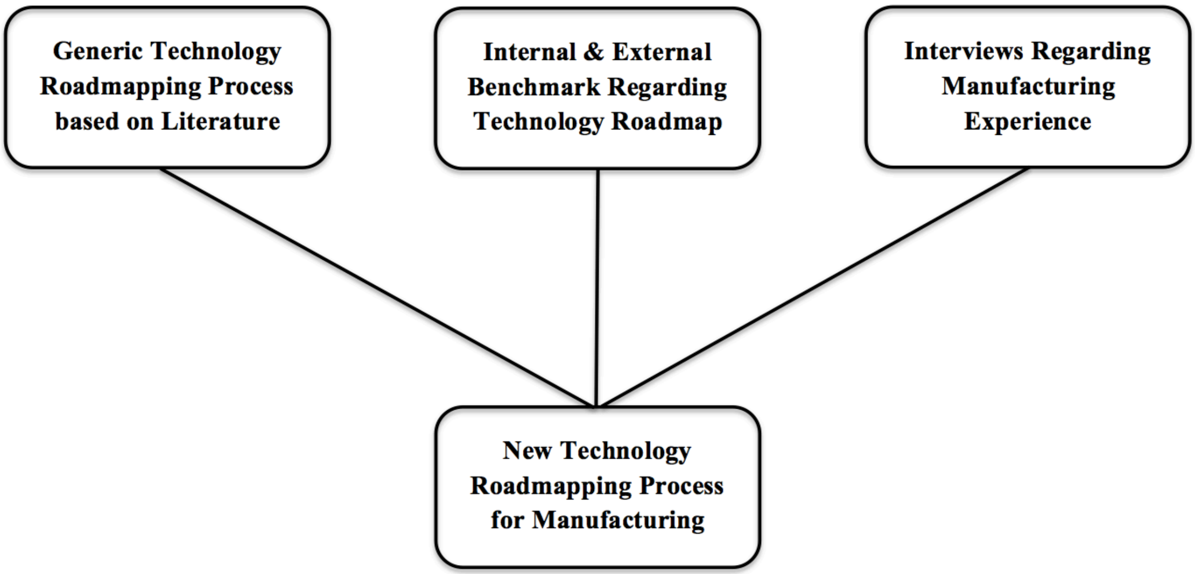

Figure 3. Three building blocks behind the new roadmapping process

2.4 Literature Review

A systematic literature review decreases the risk of research biases, which is why the approach functions as a foundation for the theoretical framework in this research project. The major objective of the systematic literature review is to provide an understandable overview of previous research and cumulative knowledge in the research area. Research based on a systematic literature review provides a solid foundation, as it thoroughly reviews existing literature and enables transparency in the research process (Bryman & Bell, 2011).

To start the systematic literature review process the researchers need to define an answerable research question and establish the process, which entails regular meetings with central stakeholders in order to clearly set boundaries for the research (Bryman & Bell, 2011). There are two main stakeholders apart from the researchers in the research project, namely the supervisor at the Institute of Innovation and Entrepreneurship at University of Gothenburg and the contact persons at department AA.

It is important to define keywords for the systematic literature review as it enables a systematic search of relevant literature and theory (Bryman & Bell, 2011). The researchers scan various scientific journals in order to collect theories from existing literature. Examples of keywords used for this research project are *Technology Roadmap, Technology Roadmapping, Innovation Roadmap, Manufacturing Development, Production Development, and Production Process Planning*. Different combinations of these keywords also allow improved search results. A number of search engines at the University of Gothenburg library enable access to these scientific journals. Examples of search engines for this research project are *Web of Science, Emerald, Springerlink, EBSCOHost, and ScienceDirect*. Bryman and Bell (2011) describes a method called snowball sampling, which means that the researcher first get in contact with a small group of people and then uses this group to get in contact with others. The literature review in this research project follows a similar approach, thus the researchers collect references mentioned in the articles identified through the search engines.

This implies that the literature review has its base in secondary information and not tertiary information, which strengthens the overall quality.

When the research scope and search criteria is defined it is time to conduct the systematic literature review and search for relevant literature to include. Existing literature on technology roadmap is explored until saturation is achieved and no additional relevant theories emerge. The literature review generates a list of literature including information regarding authors, publication year, methods, and key concepts. The collected literature is then reviewed and consolidated to a theoretical framework, which in turn forms a base for the continued research process (Bryman & Bell, 2011).

2.5 Empirical Material Collection

It is necessary to make a profound investigation of how the department works on a daily basis to create a thorough understanding of the issues the department currently faces. To understand the underlying fundamentals of existing working methods, the gathering of empirical material is a vital activity in the research project. Semi-structured interviews with respondents working at department AA provide the majority of the empirical material. The reason behind the choice of semi-structured interviews is the possibility for the researchers to ask follow-up questions and allow the respondents to drift away to some extent from the original question to completely cover the subject. However, the interview structure allows the researchers to ensure some kind of correspondence between different interviews, which in turn enables comparison and analysis of material gathered from multiple sources (Bryman & Bell, 2011). The researchers also assist department AA in the development of education material for technology roadmap, which functions as further inputs to the research project.

In addition to the empirical material from department AA, benchmarks with other internal departments at company A strengthen the empirical material. These benchmarks enable the research project to get valuable insights about the concept and how it works within other areas. The research project includes an external benchmark study to get access to information regarding how other companies use technology roadmaps and an expert consultation with the purpose to identify important manufacturing related factors. Multiple sources of empirical material provide the researchers with diverse and valuable inputs regarding technology roadmapping for manufacturing.

2.5.1 Respondent Overview

The research project consists of 17 interviews with respondents knowledgeable within either technology roadmap or manufacturing development, or both. The research project includes nine interviews at the case department AA, four interviews with respondents from other departments at company A, and four interviews with external companies. The majority of the interviews were made face to face, however due to long travel distances, some interviews were made via telephone or Skype. *Table 1* presents the respondents participating in this research project. Department AA is the case organization for this research project, while AB and AC are other departments in the same company A. Company B, C, and D are external companies. The distribution of respondents over industry, company, and functional borders as well as hierarchical levels strengthens the quality and reliability of the research project.

Table 1. Respondent table

Company Code	Respondent Code	Department	Position	Date	Interview Method	Length
B	B1	Operations	Operations Development Manager	150225	Skype	1:08
AA	AA1	Operations	Manufacturing Technology Manager	150226	Face to Face	1:29
AB	AB1	Product	Advanced Engineering Technology Leader	150303	Face to Face	1:05
AB	AB2	Product	Global Technology Manager	150304	Face to Face	1:05
AA	AA2	Operations	Manufacturing Technology Manager	150305	Telephone	1:13
C	C1	Product	Production Validation Specialist	150306	Telephone	1:02
AA	AA3	Operations	Manufacturing Technology Manager	150306	Face to Face	1:02
AA	AA4	Operations	Manufacturing Technology Manager	150313	Face to Face	1:26
C	C2	Product	Global Project Office Manager	150317	Telephone	0:53
D	D1	Operations	Operations Development Consultant	150318	Face to Face	1:02
AA	AA5	Operations	Director Assembly	150319	Face to Face	0:55
AB	AB3	Operations	Director Manufacturing Research & Advanced Engineering	150320	Face to Face	1:04
AA	AA6	Operations	Technology Manager Assembly	150323	Face to Face	0:53
AA	AA7	Operations	Vice President Manufacturing Engineering	150324	Face to Face	0:53
AC	AC1	Operations	Director Global Manufacturing Technology	150327	Telephone	0:27
AA	AA8	Operations	Manufacturing Technology Specialist Manual Assembly	150401	Face to Face	0:47
AA	AA9	Operations	Manufacturing Technology Specialist Assembly	150402	Face to Face	0:58

3 Literature Review

Following sections present a literature review on technology roadmap. Technology roadmap has two fundamental elements, namely the roadmap itself and the roadmapping process (Carvalho, Fleury, & Lopes, 2013; Kostoff & Schaller, 2001; Kappel, 2001).

There is no single standardized definition for the first element, the roadmap, and the literature provides several definitions (e.g. Daim & Oliver, 2008 pp. 690; Kajikawa, Usui, Hakata, & Yasunaga, 2008 pp. 2). However, this research project uses Galvin's (2004) definition, "*Roadmaps provide an extended look at the future of a chosen field of inquiry drawn from the collective knowledge and imagination of the groups and individuals driving change in that field*" (Galvin, 2004, pp. 101). Regarding the second element, the roadmapping process, the situation is similar with a wide array of definitions (e.g. Carvalho et al., 2013, pp. 1434). Kappel (2001) provides the definition for this research project, "*Roadmapping is the activity of creating and then communicating the roadmap*" (Kappel, 2001, pp. 41).

There is often confusion regarding the difference between strategic planning and roadmapping (Phaal, Farrukh, & Probert, 2005). In some cases, roadmapping is part of the strategy process, thus roadmaps enable communication of outputs from the strategic planning process. The more organizations start to work with roadmaps, the more roadmaps seem to affect the overall strategy process. This results in that the two activities almost become synonyms (Phaal, Farrukh, & Probert, 2005). However, technology roadmap is not a substitute for other strategic tools, however a mechanism to integrate them. Phaal, Farrukh, and Probert (2005) illuminate how the evolution of technology roadmap has broadened the purpose for companies to use it, thus it today is more of a strategic tool with the purpose to mitigate future challenges. There are other terms related to roadmapping, such as strategy, business, and innovation (Lee & Park, 2005; Phaal, Farrukh & Probert, 2004). This implies that technology roadmap is applicable to several strategic areas, however the differences lie in the details of the sub-stages in the roadmapping process. For instance, technology roadmapping consider vital steps of technology maturity assessment, which business roadmapping do not.

The literature review starts with the first element, technology roadmap, and continues with a review of the second element, technology roadmapping. The ending section presents manufacturing related factors to incorporate in technology roadmapping for manufacturing.

3.1 Technology Roadmap

Phaal, Farrukh, and Probert (2005) provide a thorough explanation of technology roadmap. The basic principle of a roadmap is to visualize potential trajectories an organization can follow in order to go from a current state to a desired future state. To enable this transition, technology roadmap has its foundation in three questions (Phaal, Farrukh, & Probert, 2005):

1. Where are we now?
2. Where do we want to go?
3. How can we get there?

The purpose of these questions is to illustrate possible trajectories towards the desired future state (Phaal, Farrukh, & Probert, 2005). The questions relate to the fundamentals behind a conventional journey, thus it is essential to know the current location, the destination, and the alternative routes in between (Daim & Oliver, 2008; Kostoff & Schaller, 2001; Simonse, Hultink & Buijs, 2014).

A roadmap is a multi-layered graphical illustration, which coordinates and communicates development activities across the organization's different departments and hierarchical levels. First, the top layer of the roadmap relates to the overall purpose of the organization and includes various trends and drivers (internal or external) affecting the organization on a strategic level. Second, the middle layer deals with specific activities to fulfill the purpose of the organization and relates to the development of products, services, and processes. Third, the bottom layer considers the resource requirements (e.g. financial, competence, & technology) of the activities in the middle layer. For instance, there has to be a link between the inputs regarding demands from the market (top layer), the activities in product and process development (middle layer), and the specific resource requirements in the bottom layer (Phaal, Farrukh, & Probert, 2005).

Ilevbare, Probert, and Phaal (2014) describe the layers with three aspects. First, know-why relates to the top layer and aims at increasing the understanding of why certain activities need to take place. Second, know-what relates to the development activities required to meet the external or internal demand. Third, know-how considers the requirements of technologies, capabilities, and resources to perform the development activities (Ilevbare, Probert, & Phaal, 2014).

Phaal, Farrukh, and Probert (2004) argue the importance of adapting the layers to the particular situation. Kerr, Phaal, and Probert (2011) mention how the roadmap creates linkages between different layers of stakeholders in an organization. In addition, they argue it is not only a communication tool to ease sharing of information, but also a way to coordinate activities efficiently. Lee, Phaal, and Lee (2011) add to this discussion that technology roadmap reaches its full potential when coordination is necessary between developments of several different technologies in several projects.

There are two main aspects of the roadmap concept, market pull and technology push. Technology push prioritizes the development of new technologies over actual market demands, while market pull starts the analysis from the market requirements and then focuses on the development of technologies required to fulfill those requirements (Karasev & Vishnevskiy, 2013; Kostoff & Schaller, 2001). Technology push enables discovery and development of promising technologies, however lacks the feature to link the technologies to actual market demands. On the other hand, market pull facilitates the investigation of future requirements from the market and other stakeholders, while failing to analyze if the internal capabilities can fulfill those requirements (Karasev & Vishnevskiy, 2013). It is a requirement to establish a clear relationship between the three layers in the roadmap and balance market requirements with the organization's internal capabilities (Phaal & Muller, 2009). In other words, it is necessary to merge market pull and technology push and let the market demands form the ground for the development activities (Garcia & Bray, 1997; Phaal, Farrukh & Probert, 2004). However, when the time horizon is too long to identify the future's actual market demands, it is necessary to make predictions and push new technologies to the market (Garcia & Bray, 1997).

If the relationship between the three layers in the roadmap can be identified, the chance of success increases (Phaal & Muller, 2009). A visualization of the layers' relationships is a logical method to test the roadmap quality (Phaal & Muller, 2009). For instance, the identification of a long-term market trend A and a medium-term market trend B triggers the development of product C, service D, and process E. In addition, these development activities require the development of technology F, which makes it necessary to make investment G.

Figure 4 presents an example of a roadmap, including the time dimension, the three fundamental questions, and the three layers. The figure also provides the example from the previous paragraph. A graphical illustration of a roadmap describes, according to Phaal, Farrukh, and Probert (2005), interdependencies and relationships between different development activities. The time dimension enables decision makers to know when to execute certain activities to eventually reach the desired future state (Phaal, Farrukh, & Probert, 2005).

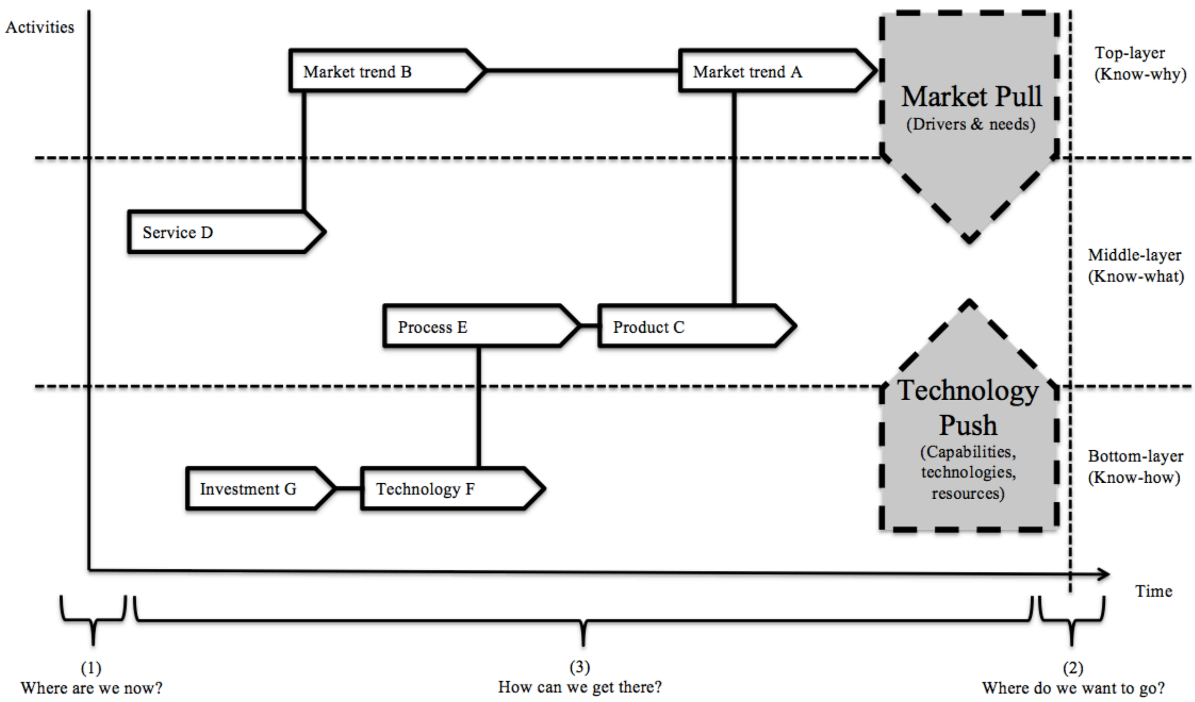

Figure 4. Illustration of the Roadmap Concept (revised from Phaal, Farrukh, & Probert, 2005)

3.1.1 Opportunities and Challenges

The roadmap concept has a number of opportunities and challenges. It has the characteristic to synchronize technological considerations with business related issues, thus it can include many different inputs (Daim & Oliver, 2008; Kostoff & Schaller, 2001; Phaal, Farrukh, & Probert, 2004; Arnold, Erner, Möckel, & Schläffer, 2010; Simonse, Hultink, & Buijs, 2014). The ability to combine long-term planning and short-term activities results in a strong decision-making tool, which can direct investments more efficiently (Lee, Phaal, & Lee, 2011; Petrick & Echols, 2004). The roadmap concept also enables identification of both knowledge gaps and opportunities for future developments, improves stakeholder communication, and stimulates a shared understanding for the surrounding business environment (Kostoff & Schaller, 2001; Daim & Oliver, 2008). Additionally, Nyhuis et al. (2010) argue roadmaps enable coordination between product, technology, and factory layout.

In a study of twelve large organizations, Simonse, Hultink, and Buijs (2014) depict three vital findings related to the roadmap concept. The research reveals the importance of connecting activities to a timeline, balancing and synchronizing short-term actions with long-term objectives, and having effective dialogues to reach consensus. There are further two main benefits with roadmaps. First, timely executions of both market entry and investments provide the organization with a competitive edge. Second, companies using roadmaps tend to reach innovation synergy effects through collaborations with other companies (Simonse, Hultink, & Buijs, 2014).

Another study conducted by Lee, Phaal, and Lee (2011) investigates 186 different R&D units in Korean companies. The result from the study reveals that successful utilization of technology roadmap is dependent upon an effective roadmapping process, organizational support, and alignment with overall company objectives.

Several aspects with technology roadmap might be challenging. For example, the quality of a roadmap relates to the quality of the input information (Phaal, Farrukh, & Probert, 2005). Kostoff and Schaller (2001) mention the difficulty of measuring the quality of the roadmap. It is not safe to say that the roadmap is of high quality just because all activities have been carried out on time, thus the roadmap may have been too easy to execute (Kostoff & Schaller, 2001). Two other recurrent problems are that companies expect short-term results and underestimate the costs of implementing the working method (Lee, Phaal, & Lee, 2011).

Kappel (2001) presents additional critique against technology roadmap. He argues there is a potential risk the roadmap becomes a policy activity where the participants follow the routines only because they are mandatory. Further, there is a risk companies adopt the concept because they think it is the right thing to do. The author means that roadmapping is not suitable for creative and disruptive action. The process is more applicable to trends and linkages between different technologies, which in turn relates more to coordination and not discovery (Kappel, 2001).

To become successful in its roadmap endeavors, the organization needs to consider vital aspects related to the concept. Jeffrey, Sedgwick, and Robinson (2013) found a number of key success factors vital to consider. First, it is necessary to involve the right people representing a broad range of stakeholders. Second, to consider the roadmap users as key stakeholders, thus it increases the chance of realization of the roadmap's activities. Third, to keep the roadmap up to date is essential to gain momentum in the process. Fourth, it is vital to establish clear goals in the beginning of the process as a way to enable prioritization. Fifth, to have a clear work-structure, layout, and visualization, thus it increases efficiency (Jeffrey, Sedgwick, & Robinson, 2013). Kostoff & Schaller (2001) add to these factors the commitment from senior management, an appropriately defined role of the roadmap manager, high competence among roadmap developers, and a standardized roadmapping process.

Phaal, Farrukh, and Probert (2005) emphasize roadmaps occasionally tend to make organizations over confident regarding future outcomes. Technology roadmap sometimes creates a false sense of certainty and a belief in that the completion of predetermined activities automatically leads to the fulfillment of goals. Therefore, a critical and holistic view is of great importance when working with roadmaps, thus it otherwise is easy to end up at the wrong path (Phaal, Farrukh, & Probert, 2005). The roadmap itself is quite simple in its graphical format, however the underlying process might be challenging. The roadmapping process needs careful consideration before an organization introduces the concept (Phaal, Farrukh, & Probert, 2004).

3.1.2 Customization of Technology Roadmap to fit in the Organization

All organizations have different structures, contexts, cultures, processes, resources, and competitive environments (Phaal, Farrukh, & Probert, 2004). However, the technology roadmap described in existing literature is quite general, which means that it probably needs some customization to fit into a specific organization. The following aspects, mentioned by Phaal, Farrukh, and Probert (2004), requires consideration before technology roadmap is introduced in an organization.

Time

Time is an issue in need of attention when the organization customizes the roadmap to its context. First, different organizations and industries need different time horizons in their roadmaps. Fast moving industries, e.g. e-commerce, probably require shorter time horizons than slow moving industries, such as aerospace and infrastructure (Phaal, Farrukh, & Probert, 2004). The time requirements of the activities in the roadmap should influence its time horizon, thus they set the boundaries for when it is possible to reach a desired future state (Kappel, 2001). Second, the roadmap's time scale can be adapted to provide more focus on short-term than long-term aspects. For instance, in a roadmap with a five-year time horizon, the first half of the roadmap focuses on the first year and the other half on the remaining four years. Finally, it is possible to include the past (e.g. the most recent year) to get a clear picture over the current state of the organization (Phaal, Farrukh, & Probert, 2004).

Roadmap Layers

Phaal, Farrukh, and Probert (2004) argue the layers depicted on the vertical axis in the roadmap require customization. The top layer should relate to the organization's purpose (e.g. market, customers, trends, strategy etc.), the bottom layer to the available resources, and the middle layer to activities that use the resources to fulfill the purpose (Phaal, Farrukh & Probert, 2004).

Annotation

To make the roadmap easy to interpret, it is necessary to consider its graphical illustration. It needs to be apparent how different activities relate to each other via linkages and which people should be involved in each activity. Color-coding and notes shows the most important activities, potential challenges, threats, and decision points. Hence, the graphical design of the roadmap is important to increase understandability (Phaal, Farrukh, & Probert, 2004).

Process

The roadmapping process itself needs customization to fit in the organization. The implementation of technology roadmap requires certain resources and competences, which implies that different organizations have varying opportunities to introduce it. The roadmapping process also requires customization to fit with other strategic processes in the organization, thus it is essential that all processes drive the organization in the same strategic direction (Phaal, Farrukh, & Probert, 2004). Consequently, the focus of the upcoming section is the roadmapping process, which relates to the second research sub-question in this research project.

3.2 Technology Roadmapping

A common opinion is that roadmapping, the process to produce the roadmap, is more valuable than the actual roadmap. Social interactions between participants create consensus regarding the organization’s future (Phaal & Muller, 2009). Existing literature on technology roadmapping introduces a number of processes, which take somewhat different approaches. Several articles present the complete roadmapping process, stretching from organizational preparation to roadmap delivery. However, as organizational preparation falls outside the scope of this research project, the literature review excludes such activities. The following sections only present the activities directly related to the project's scope, which is the development and follow-up of the roadmap content.

Furthermore, three articles (Garcia & Bray, 1997; Arnold et al., 2010; Daim & Oliver, 2008) put attention to two main phases in the roadmapping process, namely roadmap development and roadmap follow-up. These phases form the ground for the roadmapping process, which the following sections describe. On the other hand, a number of other articles (Vishnevskiy, Karasev, & Meissner, 2015; Phaal & Muller, 2009; Karasev & Vishnevskiy, 2013; Yamashita, Nakamori, & Wierzbicki, 2009; Hasse, Birke, & Schwarz, 2012) put articulated focus exclusively on the first phase, roadmap development. These articles present a number of recurrent features in the roadmapping process, which through codification forms a generic roadmapping process functioning as a framework for the upcoming empirical findings and analysis. *Table 2* presents the codification of the articles and their roadmapping processes to fit into the technology roadmapping process chosen to be the framework for this research project.

Table 2. Codified Technology Roadmapping Process

Codified Technology Roadmapping Process	**Technology Roadmapping stages from literature**
1. Technology Roadmap Development	– Development of the Roadmap (Garcia & Bray, 1997) – Foresighting & Roadmapping (Vishnevskiy, Karasev, & Meissner, 2015) – Environmental Analysis, Scenario Development, & Roadmap Development (Arnold et al., 2010) – Ideation, Divergence, Convergence, & Synthesis (Phaal & Muller, 2009) – Pre-Roadmapping, Desk Research, Expert Procedures, Creative Analysis, Interactive Discussion (Karasev & Vishnevskiy, 2013) – Roadmap Development (Daim & Oliver, 2008) – Intervention, Intelligence, Involvement, Imagination, & Integration (Yamashita, Nakamori, & Wierzbicki, 2009) – Scoping, Forecasting, Backcasting, & Roadmapping (Hasse, Birke, & Schwarz, 2012)
2. Technology Roadmap Follow-up	– Follow-up Activity (Garcia & Bray, 1997) – Navigation Board Development (Arnold et al., 2010) – Roadmap Review (Daim & Oliver, 2008)

The result of the codification is the technology roadmapping process, which is a consolidated version of the processes from the literature. Technology roadmap often requires the development and coordination of roadmaps on different hierarchical levels and Phaal and Muller (2009) put emphasis on the iterations of roadmaps between such levels. A predefined time interval enables feedback on the roadmap content and suggestions on how to improve it. Daim and Oliver (2008) imply the cyclical process of roadmap development and follow-up makes it easier to keep the roadmap content up to date.

The technology roadmapping process in *figure 5* starts with phase one, *technology roadmap development*, which consists of five sub-stages. The first sub-stage, *prerequisites*, explains the context, scope, and boundaries for the overall roadmapping process. The second sub-stage, *current state*, aims at defining where the organization is right now in terms of technologies, market position, competitors etc. The third sub-stage, *future state*, sets the overall target for where the organization wants to position itself in the future. In the fourth sub-stage, *strategy*, the organization explores different alternative ways of reaching the future state. The actual suggestion for which trajectories to pursue with is presented in the fifth sub-stage, *roadmap report*, which is delivered to the management team. The first phase, technology roadmap development, is often performed on lower levels in the organization and further passed on upwards to management level.

In the second phase, *technology roadmap follow-up*, managers scrutinize the composed technology roadmaps from phase one in order to find the most promising suggestions to implement. The first sub-stage in this phase is *roadmap validation*, which purpose is to either approve or reject the roadmap. Further, the second sub-stage, *roadmap review*, aims at monitoring progression of each approved technology roadmap. Lessons learned during development and follow-up of technology roadmaps becomes important inputs to the next generation of technology roadmaps.

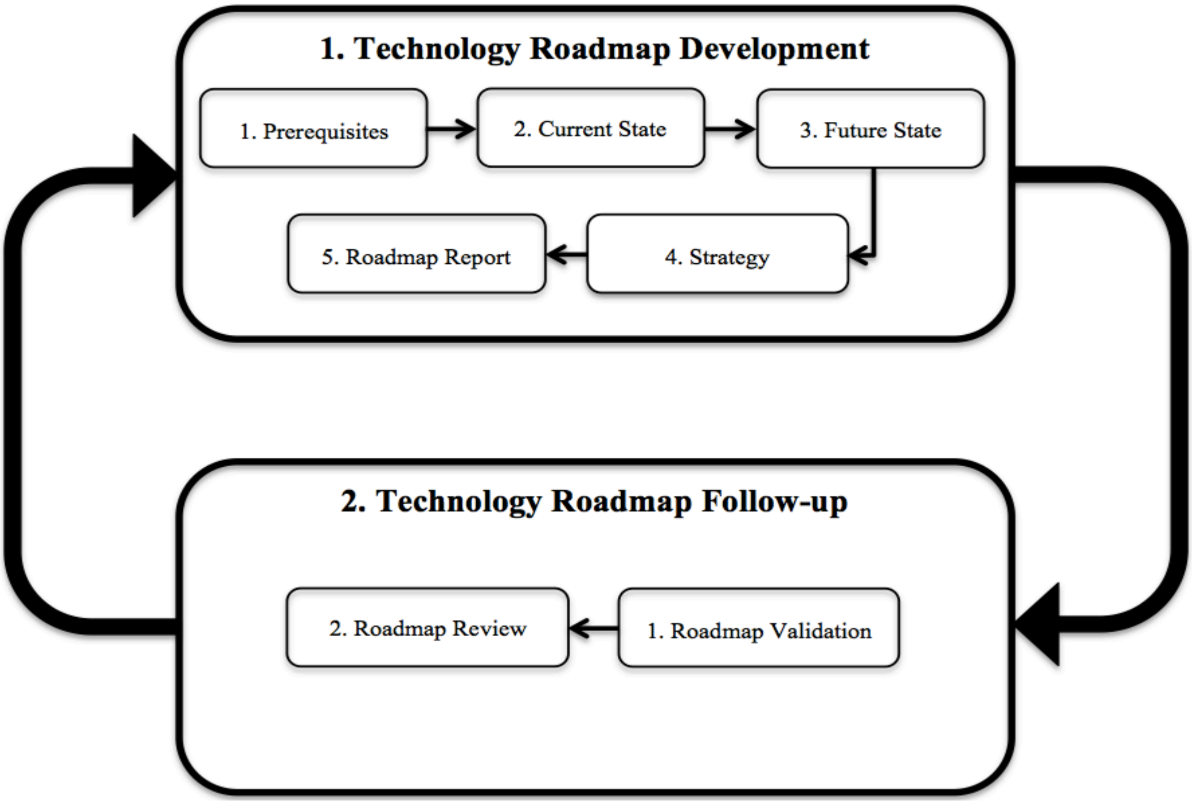

Figure 5. The Technology Roadmapping Process

3.2.1 Phase 1: Technology Roadmap Development

The first phase in the roadmapping process aims at the development of the roadmap itself and consists of five sub-stages.

Sub-stage 1: Prerequisites

It is important to establish a number of prerequisites before the development of the roadmap content. *Figure 6* and subsequent paragraphs present and explain the activities in this stage.

1. Prerequisites

- Define the roadmap's context, scope, and boundaries
- Set the roadmap design
- Select an appropriate time horizon
- Ensure the roadmap's connection to other strategic tools
- Use cross-functional collaborations
- Customize the roadmapping process to the organization's needs
- Create organizational understanding for the roadmapping process

Figure 6. Activities in the prerequisites sub-stage

Initially it is vital to define the context, scope, boundaries, and design for the roadmap (Garcia & Bray, 1997; Phaal & Muller, 2009). Phaal and Muller (2009) depict the importance of the first sub-stage, thus the remaining process relies largely on the clarity in this stage. Garcia and Bray (1997) argue the purpose is to define the context in which technology roadmap should be applied, and how the organization should use the information provided in the roadmap. Part of this is to identify the needs and decide upon an appropriate time horizon (Garcia & Bray, 1997). As roadmapping is an iterative and cyclical process, it is vital to include information from earlier iterations in this stage to ensure progress towards the future state (Phaal & Muller, 2009).

The roadmap needs linkages to other strategic planning processes, thus it otherwise is problematic for the concept to achieve maximum impact (Phaal, Farrukh, & Probert, 2005; Kostoff & Schaller, 2001). The value of differing perspectives, cross-functional collaborations, and inter organizational relationships should not be underestimated, which emphasize the importance of a proper team composition (Garcia & Bray, 1997; Kostoff & Schaller, 2001; Kerr, Phaal & Probert, 2011; Strauss & Radnor, 2004). Yamashita, Nakamori, and Wierzbicki (2009) take a societal perspective and argue the main benefit of the roadmapping process is the social interactions between individuals. Two important factors are to reach societal motivation among team members and consensus regarding future actions. The roadmap development team needs a deep understanding of the motivation behind the concept. The team has to receive knowledge about the technology roadmap itself, its purpose, and the process behind it. Every member has to understand its role in the group and be aware of the time boundaries (Yamashita, Nakamori, & Wierzbicki, 2009).

The prerequisite sub-stage includes a customization of the roadmapping process to ensure compatibility between the stages in the process and the organization's routines and structures. It is also essential to decide upon how to maintain and update the roadmapping process to remain relevant (Phaal, Farrukh, & Probert, 2005; Yamashita, Nakamori, & Wierzbicki, 2009). It has to be easy for users to access information about the roadmapping process as it increases understandability, involvement, and participation (Yamashita, Nakamori, & Wierzbicki, 2009). A software-based roadmapping process can enable easier access to updated information and enhance user friendliness. The roadmapping software should be able to locate, analyze, and combine different kind of data to reach the full benefit (Lee, Phaal, & Lee, 2011).

Sub-stage 2: Current State

Figure 7 introduces the activities involved in the definition of the current state. Existing literature on the subject lacks proper explanations on methods to define the current state in the roadmap. The literature only says that it is important to define the current state, but unfortunately not how to do it. The researchers' ambition is to find answers on the execution of this sub-stage in the empirical findings.

2. Current State

- Define the current state in terms of technologies, resources, and competences
- Identify the basic conditions in which the organization operates

Figure 7. Activities in the current state sub-stage

To enable roadmap development, it is vital to identify and investigate the circumstances around the roadmap. The organization needs to define the current state, thus it is necessary to describe where the organization positions itself right now (Hasse, Birke, & Schwarz, 2012; Garcia & Bray, 1997). To express the current state is crucial, as it puts emphasis on the current basic conditions within the organization. This relates to the first question mentioned by Phaal, Farrukh, and Probert (2005), which is "Where are we now?". The question considers the organization’s current state in terms of, for instance, technologies, resources, and competences. This step is vital as it is problematic to identify the strategy towards a future state if the current state is unknown and not defined.

Sub-stage 3: Future State

In the roadmapping process, it is necessary to depict the desired future state (Hasse, Birke, & Schwarz, 2012; Garcia & Bray, 1997). It relates to the second question mentioned by Phaal, Farrukh, and Probert (2005), "Where do we want to go?". Without a clear picture of the future state, it is difficult to set the strategy because the organization does not know in which direction to go (Phaal, Farrukh, & Probert, 2005). *Figure 8* and the following paragraphs present the activities in this sub-stage.

3. Future State

- Analyze the environment
- Develop multiple scenarios
- Involve external actors to analyze the future
- Develop consensus in the organization regarding the future state
- Use foresighting to define the future state

Figure 8. Activities in the future state sub-stage

The environmental analysis described by Arnold et al. (2010) is an appropriate method to define the future state, thus it enables identification of important drivers for the market, customers, and political and technological environment. The analysis should not only include factors directly affecting the core business, but also factors related to trends in similar industries and the surrounding environment as a whole (Arnold et al., 2010).

It is always difficult to predict the future and this has implications for the roadmapping process. To hedge itself for future uncertainties and hence be flexible in its development efforts, the organization needs to identify a number of scenarios and estimate their probabilities (Saritas & Aylen, 2010). Arnold et al. (2010); Hasse, Birke, and Schwarz (2012); and Garcia and Bray (1997) mention the importance of using scenarios as a method to depict alternative futures. Strauss and Radnor (2004) argue simultaneous execution of scenario development and roadmapping enables the organization to reap benefits from both methods.

It is appropriate to organize brainstorming sessions and debates with central stakeholders to enable scenario development (Yamashita, Nakamori, & Wierzbicki, 2009; Phaal & Muller, 2009). Kerr, Phaal, and Probert (2011) argue the strength with roadmapping emerges in the interactions between group members with heterogeneous backgrounds. Strauss and Radnor (2004) mention how such interactions trigger the emergence of differing perspectives, which in turn is positive for the reliability of the scenarios. However, it is not enough to exclusively include internal actors in this stage, thus external actors' (e.g. researchers, industry experts, suppliers, & customers) experiences might be of high value to consider (Daim & Oliver, 2008; Garcia & Bray, 1997; Kostoff & Schaller, 2001; Yamashita, Nakamori, & Wierzbicki, 2009). The roadmap's quality is dependent upon its inputs, which makes it essential to put effort into this step. Involvement of external actors through, for instance, delphi-surveys and workshops are examples on how to improve the input quality (Karasev & Vishnevskiy, 2013; Phaal & Muller, 2009). Yet, inputs from such actors are not enough and it is necessary to look into existing literature to create a strong theoretical foundation (Karasev & Vishnevskiy, 2013; Yamashita, Nakamori, & Wierzbicki, 2009). Hasse, Birke, and Schwarz (2012) emphasize the importance of screening existing knowledge in the organization and search for gaps in resources and capabilities. This information is essential for the remaining part of the roadmapping process (Hasse, Birke, & Schwarz, 2012).

Garcia and Bray (1997) highlight the importance of creating consensus regarding the future state. It is important to receive acceptance for the roadmap from different actors in the organization, which once again puts attention to the necessity to involve the right people. Karasev and Vishnevskiy (2013) add that interviews with experts enable access to their practical experience, which is difficult to find in literature. These interviews should form the basis for discussions regarding markets, products, and technologies to reach consensus among the stakeholders (Karasev & Vishnevskiy, 2013). The use of graphical presentation tools, simulations, debates, and brainstorming sessions stimulate individuals' creativity and facilitate definition of the future state (Yamashita, Nakamori, & Wierzbicki, 2009).

Vishnevskiy, Karasev, and Meissner (2015) take a somewhat different approach to define the future state and underline the strengths of combining foresighting and roadmapping. The main advantage with foresighting is that it enables companies to identify the long-term indicators for changes in demand. Foresighting is a method to predict the future state, while roadmapping is a tool to map up the strategy to reach the future state. The focus in the foresighting process lies on the creation of an expert group with the right competences, which is capable to foresee future trends. The group uses benchmarking, interviews, brainstorming sessions, SWOT-analyses, and expert panels to get access to as much information as possible about trends, drivers, and barriers within the specific field of inquiry. The group analyzes promising future technologies (technology push) simultaneously as it outlines probable dynamics for future markets (market pull). The products of the foresighting process are guidelines and priorities for the upcoming roadmap development (Vishnevskiy, Karasev, & Meissner, 2015). *Figure 9* illustrates the fundamentals in the foresighting process and how it provides prioritization guidelines for the roadmap development.

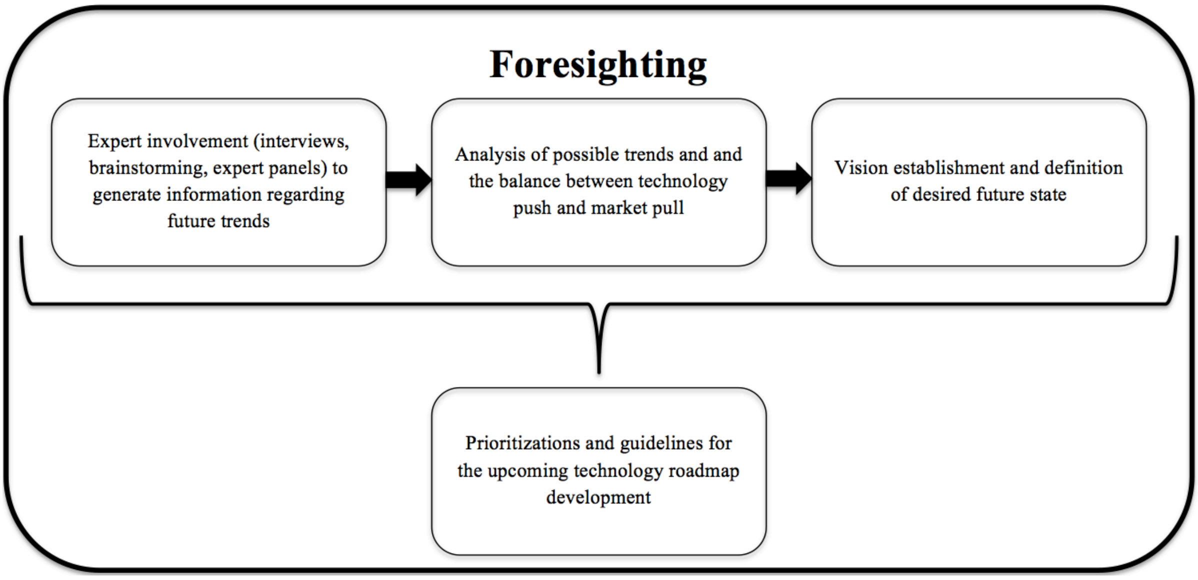

Figure 9. The role of foresighting in the roadmapping process (revised from Vishnevskiy, Karasev, & Meissner, 2015).

Sub-stage 4: Strategy

The strategy sub-stage has the purpose to map up the path between the current and future state. The strategy relates to the question "How can we get there?" (Phaal, Farrukh, & Probert, 2005). Vishnevskiy, Karasev, and Meissner (2015) illuminate how the future state works as a guideline and sets the boundaries for the strategy development. Garcia and Bray (1997) put emphasis on the identification of critical system requirements and targets, which becomes a quantified version of the future state. For instance, a system requirement for a manufacturing process could be increased energy efficiency and its target a ten percent reduction of energy consumption.

Daim and Oliver (2008) mention that the strategy includes necessary development activities to reach the future state in terms of costs and performance for a specific technology. Phaal and Muller (2009) highlight the need to make the content in this sub-stage interpretable for key stakeholders. Consolidation of the vast amount of material from various brainstorming sessions and workshops increase understandability and enable further analysis. A small team gets the assignment to consolidate the information and visualize the most important risks, opportunities, and trends for a specific technology area (Phaal & Muller, 2009; Vishnevskiy, Karasev, & Meissner, 2015). The focus lies on the technologies required to reach the system requirements and their targets (Garcia & Bray, 1997).

Figure 10 illustrates the major building blocks in this sub-stage, which are the identification of necessary activities to bridge the gap between the current and future state, evaluation of alternative technologies and parallel tracks, technology maturity assessment, and risk analysis. The product is a time-based activity list, which represents the strategy.

4. Strategy

- Identify necessary activities through backcasting
- Use parallel tracks as a hedge against uncertainty
- Assess technology maturity
- Manage risks in the roadmap

Figure 10. Activities in the strategy sub-stage

Backcasting enables identification of possible routes between the future and current state. The future state is the starting point in the backcasting process and all activities are mapped up backwards to create an action plan (Arnold et al., 2010; Karasev & Vishnevskiy, 2013; Hasse, Birke, & Schwarz, 2012). As market demand is the foundation for the future state, the backcasting methodology relates to the market pull approach (Kostoff & Schaller, 2001). The activities follow the same structure as the roadmap's different layers and involvement of all stakeholders is vital to identify relationships between activities in the roadmap (Arnold et al., 2010).

Phaal and Muller (2009) describe the necessity to investigate information in detail to define each activity generated by the backcasting process. Trends, technologies, and risks are examples of factors to consider in the process of outlining possible routes (Phaal & Muller, 2009; Yamashita, Nakamori, & Wierzbicki, 2009). Thorough analysis of every option facilitates identification of necessary R&D activities behind critical technologies (Daim & Oliver, 2008; Garcia & Bray, 1997; Karasev & Vishnevskiy, 2013).

As the future is ambiguous and hard to predict, it might become necessary to run development activities in parallel to safeguard the organization for uncertainties regarding future technology and market trends. It is vital to identify these alternatives and evaluate their respective development time lines, which is an assessment of their maturity. If the development of a specific technology lags behind it is necessary to abandon the technology for another alternative (Garcia & Bray, 1997).

It takes time and resources to develop new technologies, thus each technology goes through an evolutionary process in which the maturity develops over time. To be competitive, any company needs to appreciate the maturity of various technology alternatives based on its internal resources and competences. The roadmapping process should therefore include an element of technology maturity assessment, which enables the organization to estimate the development time of a certain technology (Greitemann, Christ, Matzat, & Reinhart, 2014). It is necessary to set up targets and specifications of dates when certain technology drivers need to have reached their desired states (Garcia & Bray, 1997).

Vishnevskiy, Karasev, and Meissner (2015) mention that the organization should evaluate existing resources and capabilities and make a decision regarding activities to insource or outsource. If the organization is too immature to pursue a certain activity, it might become relevant to let an external actor perform the activity instead (Vishnevskiy, Karasev, & Meissner, 2015). Greitemann et al. (2014) and Mankins (1995) describe a tool called Technology Readiness Level (TRL), which evaluates technology alternatives for products based on their readiness level and the organization's maturity in terms of internal capabilities and competencies. The Department of Defense (2011) presents another systematic tool, Manufacturing Readiness Level (MRL), which purpose is to define maturity levels in manufacturing processes. The purpose with MRL is to identify and mitigate manufacturing risks related to new technologies. The MRL and TRL-scale require parallel consideration, thus it is vital to ensure manufacturability of the new product technology.

Both the TRL and the MRL-scale stretches from an initial idea on a piece of paper to implementation of a working technical solution. Five overall phases work as milestones or gates to ensure that the technology reaches the predefined readiness level before moving on to the next phase (Department of Defense, 2011). *Figure 11* illustrates the relation between TRL and MRL.

Pre-Concept Refinement			Concept Refinement	Technology Development		System Development & Demonstration		Production & Deployment	
MRL 1 Manufacturing Feasibility Assessed	**MRL 2** Manufacturing Concepts Defined	**MRL 3** Manufacturing Concepts Developed	**MRL 4** Manufacturing Processes in Lab Environment	**MRL 5** Components in Production Relevant Environment	**MRL 6** System or Subsystem in Production Relevant Environment	**MRL 7** System or Subsystem in Production Representative Environment	**MRL 8** Pilot Line Demonstrated Ready for Low Rate Initial Production	**MRL 9** Low Rate Initial Production Demonstrated Ready for Full Rate production	**MRL 10** Full Rate Production Demonstrated Lean Production Practices in Place
TRL 1 Basic Principles Observed	**TRL 2** Concept Formulation	**TRL 3** Proof of Concept	**TRL 4** Breadboard in Lab	**TRL 5** Breadboard in Representative Environment	**TRL 6** Prototype in Representative Environment	**TRL 7** Prototype in Operational Environment		**TRL 8** System Qualification	**TRL 9** Mission Proven

Figure 11. Manufacturing Readiness Level (Revised from Morgan, 2008)

Risks appear on different aggregation levels, both on a long-term holistic level regarding the future and on a short-term activity level. Ilevbare, Probert, and Phaal (2014) emphasize the importance of risk-aware roadmapping and describe a roadmapping process including efficient risk management. They suggest execution of risk identification, assessment, and treatment in each phase of the roadmapping process. Identification of ambiguous factors earlier in the process results in a preventive approach to mitigate risks. Ilevbare, Probert, and Phaal's (2014) study reveals that the majority of companies find risks and uncertainties most prevalent in the top and bottom layer of the roadmap. Risks in the top layer relate to uncertainties regarding future market demands while risks in the bottom layer relate to the uncertainty embedded in specific technology development activities. As risk origin from the top and bottom of the roadmap, it becomes problematic to identify the activities in the middle layer with certainty. Therefore, risk management is an essential element of the roadmapping process (Ilevbare, Probert, & Phaal, 2014). The *Figure 12* illustrates the risk management activities that should take place in each phase of the technology roadmapping process.

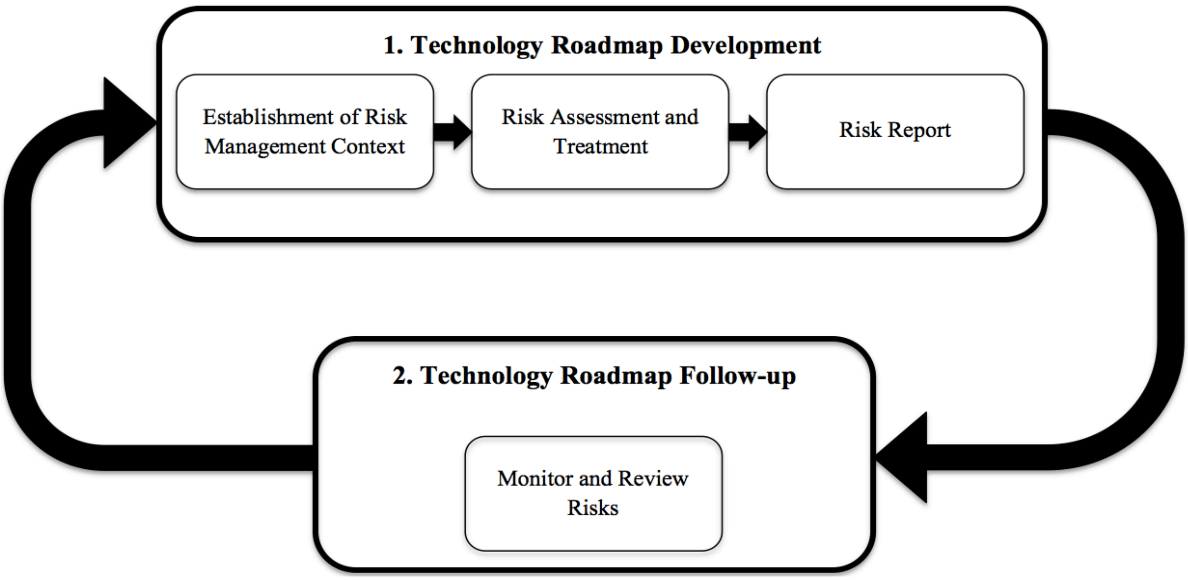

Figure 12. Risk Management in Technology Roadmapping (revised from Ilevbare, Probert, & Phaal, 2014).

Sub-stage 5: Roadmap Report

The final sub-stage in the first phase is to provide the management team with a roadmap report of trajectories to pursue in the future. The final roadmap works as a strategic plan for further actions to reach the future state (Vishnevskiy, Karasev, & Meissner, 2015; Hasse, Birke, & Schwarz, 2012). *Figure 13* presents the activities in the sub-stage roadmap report.

5. Roadmap Report

- Deliver an easy-to-understand roadmap to control entity
- Make a description of each alternative's current state, development time, resource requirements, and implementation plan

Figure 13. Activities in the roadmap report sub-stage

Reduction of the roadmap content to only include the most vital information from previous stages is necessary. This stage is much about packaging, thus the delivery needs to be adapted to the target audience. The goal is to deliver a comprehensive material, which enables managers to make decisions based on appropriate information (Phaal & Muller, 2009; Yamashita, Nakamori, & Wierzbicki, 2009).

The report should include information enabling decision makers to prioritize among different alternatives (Garcia & Bray, 1997; Phaal & Muller, 2009). The report includes descriptions of each technology's status, development time, resource requirements, and implementation plan (Garcia & Bray, 1997; Kostoff & Schaller, 2001).

Karasev and Vishnevskiy (2013) add the importance of discussing the results with experts and central stakeholders. Finally, the roadmap report should include a graphical illustration of the roadmap itself and a clear implementation plan of the upcoming steps in the process (Garcia & Bray, 1997; Hasse, Birke, & Schwarz, 2012).

3.2.2 Phase 2: Technology Roadmap Follow-up

The second phase in the roadmapping process has the purpose to follow up the roadmap content and consists of the two sub-stages roadmap validation and roadmap review.

Sub-stage 1: Roadmap Validation

The first sub-stage is to validate the roadmap and develop an implementation plan and *figure 14* presents the activities in the sub-stage.

1. Roadmap Validation

- Expose the roadmap to central stakeholders
- Prioritize among the different roadmaps
- Make decision to either accept or reject the roadmap
- Implement the roadmap through projects if it gets accepted
- Send back the roadmap for revision if it gets rejected

Figure 14. Activities in the roadmap validation sub-stage

A rather small group of people developed the roadmap during the first phase and in this sub-stage, the roadmap is exposed to a large group of stakeholders with the authority to accept or reject the implementation of the roadmap. Workshops with key stakeholders aiming at a decision whether or not to implement the roadmap is a major part of this sub-stage. In case of rejection, it is necessary to revise the roadmap and reconsider its content (Garcia & Bray, 1997).

The sub-stage includes an element of prioritization among both the different departments' roadmaps and the specific activities in each roadmap. Due to restricted resources, the organization cannot execute every suggested activity in all roadmaps and has to prioritize among them (Daim & Oliver, 2008).

If the roadmap is accepted, the process goes on towards the development of an implementation plan. The implementation is carried out on project basis, where each project is responsible for the development of a specific technology (Garcia & Bray, 1997). The eventual product of this sub-stage is a list of roadmaps to implement.

Sub-stage 2: Roadmap Review

The roadmap is not definitive and needs constant reviews by key stakeholders to remain valid (Garcia & Bray, 1997; Daim & Oliver, 2008; Ilevbare, Probert, & Phaal, 2014; Kostoff & Schaller, 2001). The sub-stage includes three main activities, which *figure 15* and upcoming paragraphs present.

2. Roadmap Review

- Review the roadmap in predefined intervals
- Update the roadmap when new information emerges
- Assign a navigation board the responsibility to monitor the progress of the activities in the roadmap

Figure 15. Activities in the roadmap review sub-stage

Garcia and Bray (1997) and Ilevbare, Probert, and Phaal (2014) argue when uncertainties about the future are better understood and toned down, it is necessary to update the roadmap with new information. This is a way to ensure that the roadmap always is up to date and incorporates the knowledge available in the organization. One alternative is to review the roadmap in the same intervals as the organization's normal planning cycle (Garcia & Bray, 1997). Daim and Oliver (2008) suggest repetition of this step on quarterly or annual basis, depending on the circumstances and how often the departments update their roadmaps.

Arnold et al. (2010) add to the discussion the necessity to assign responsibilities regarding monitoring and navigating. To ensure progression towards the future state, a navigation board gets the mission to monitor the development activities in the roadmap. The board defines a number of indicators, which works as navigation tools for the roadmap progress. If deviation from the roadmap occurs, it is essential to have action plans in place that re-navigate the developments towards the future state (Arnold et al., 2010).

3.3 Technology Roadmapping for Manufacturing

To find an answer to the third research sub-question "Which factors related to manufacturing need to be considered in Technology Roadmapping?", there is a need to identify factors related to manufacturing to incorporate in technology roadmapping for manufacturing. Vielhaber and Stoffer (2014) argue that product and manufacturing development are quite similar in terms of principal work methods, however some detail differences separates the two activities from each other. The researchers in this research project have the ambition to identify such details that characterize manufacturing development and include them in technology roadmapping for manufacturing.

The technology roadmapping process in previous sections is generic in the sense that it does not specifically relate to neither product nor process development. However, Gindy, Cerit, and Hodgson (2006) present a methodology on technology roadmapping for manufacturing with the aim to discover new technologies with the potential to generate competitive advantages. The overall purpose with the process is to break down the product architecture and identify required manufacturing technologies for each module or component. Existing and future manufacturing technologies should be scrutinized, ranked, and prioritized from a technology maturity perspective. The prioritization of technologies results in a project generation phase where different technology projects are evaluated in order to optimize the project portfolio (Gindy, Cerit, & Hodgson, 2006). However, the article only emphasizes that manufacturing should be considered from a product perspective and insufficiently discusses details of technology roadmapping for manufacturing.

One alternative to technology roadmapping for manufacturing is Modular Production Architectures (MPA) described by Kampker, Burggräf, Deutskens, Maue, and Förstmann (2014). The authors emphasize that companies today face the challenge of handling complex parallel development processes. The complexity often relates to increased cost pressure, increased product variety, increased technical product complexity, and shortened development cycles. The MPA approach starts from the product architecture were the product design is broken down to detail level. Interviews with individuals with manufacturing experience have the purpose to find the most suitable manufacturing process for the specific product components. The identification of best practice manufacturing for each sub-process functions as input to the product design to increase manufacturability (Kampker et al., 2014).

The traditional approach to technology development in a manufacturing company is that product development is superior to manufacturing development (Annacchino, 2007; Vielhaber & Stoffels, 2014). This implies that manufacturing has to make adaptions to its processes to enable manufacturing of new products. The consequences of neglecting manufacturing in product development can be devastating for the organization and result in missed market opportunities (Annacchino, 2007). Manufacturing development must therefore take place in parallel of product development to optimize chances of success because the manufacturing processes represent a substantial fraction of total costs. In other words, the traditional perspectives in product development of design, functionality, and costs have to be extended to include a factor of manufacturability to ease manufacturing of new products (Annacchino, 2007; Shehab & Abdalla, 2001).

The researchers of this research project suspect, based on the arguments by the authors in previous paragraphs, that technology roadmapping for manufacturing needs to incorporate an articulated element of parallel product and process development to optimize future performance. Another suspicion with support from Vielhaber and Stoffer (2014) and Nyhuis et al. (2010) are that the issues of factory layout planning, production sequencing, and change management are of great importance in technology roadmapping for manufacturing.

Previous paragraphs introduced some manufacturing factors, however the researchers rely on the empirical findings of this research project to identify additional examples of such factors. The researchers' ambition is to bridge the gap in existing literature and define a technology roadmapping process explicitly proposed for use in manufacturing development. One purpose with the interviews with respondents knowledgeable within both technology roadmapping and manufacturing development is to identify such factors.

3.4 Literature Table

Table 3 presents an overview of the main references in the literature review. The table introduces the reference name, research method, and content in terms of technology roadmap, technology roadmapping, and manufacturing. These references form the foundation for the theoretical framework in this research project, which in turn is the ground for the interview questions in the empirical material collection.

Table 3. Main references in the literature review

References	Theoretical Research	Empirical Research	Technology Roadmap	Technology Roadmapping: Technology Roadmap Development	Technology Roadmapping: Technology Roadmap Follow-up	Manufacturing
Annacchino (2007)	◆					◆
Arnold, Erner, Möckel, & Schläffer (2010)	◆	◆		◆	◆	
Carvalho, Fleury, & Lopes (2013)	◆		◆	◆	◆	
Daim & Oliver (2008)	◆	◆	◆	◆	◆	
Galvin (2004)	◆		◆			
Garcia & Bray (1997)	◆	◆	◆	◆	◆	
Gerdsri, Vatananan, & Dansamasatid (2009)	◆	◆	◆			
Gindy, Cerit, & Hodgson (2006)	◆	◆				◆
Greitemann, Christ, Matzat, & Reinhart (2014)	◆	◆		◆		
Hasse, Birke, & Schwarz (2012)	◆	◆		◆		
Ilevbare, Probert, & Phaal (2014)	◆	◆	◆	◆	◆	
Jeffrey, Sedgwick, & Robinson (2013)	◆	◆	◆			
Kajikawa, Usui, Hakata, Yasunaga, & Matsushima (2008)	◆	◆	◆			
Kampker, Burggräf, Deutskens, Maue, & Förstmann (2014)	◆					◆
Kappel (2001)	◆	◆	◆			
Karasev & Vishnevskiy (2013)	◆	◆	◆	◆		
Kerr, Phaal, & Probert (2012)	◆		◆	◆		
Kostoff & Schaller (2001)	◆		◆	◆	◆	
Lee & Park (2005)	◆		◆			
Lee, Phaal, & Lee (2011)	◆	◆	◆	◆		
Nyhuis, Wulf, Klemke, & Hirsch (2010)	◆		◆			
Petrick & Echols (2004)	◆		◆			
Phaal and Muller (2009)	◆		◆	◆		
Phaal, Farrukh, & Probert (2004)	◆	◆	◆			
Phaal, Farrukh, & Probert (2005)	◆		◆	◆		
Saritas & Aylen (2010)	◆	◆		◆		
Shehab & Abdalla (2001)	◆	◆				◆
Simonse, Hultink, & Buijs (2014)	◆	◆	◆			
Strauss & Radnor (2004)	◆			◆		
Vielhaber & Stoffels (2014)	◆					◆
Vishnevskiy, Karasev, & Meissner, (2015)	◆	◆	◆	◆		
Yamashita, Nakamori, & Wierzbicki (2009)	◆			◆		

4 Empirical Findings

The following sections present the empirical material from the internal case department AA, the internal benchmarks at department AB and division AC, the external benchmarks at company B and C, and the expert consultation at company D. The section starts with short introductions of the respondent companies and departments and continues with the empirical findings for each one of the research project's fundamental building blocks from the research questions and literature review.

4.1 Company A

Company A is a multinational company with several divisions active in different business areas. The company employs approximately 100 000 people and had a turnover of almost 300 billion SEK in 2014.

4.1.1 Internal Case Department AA

The focus area for this research is the internal case at department AA, which is a department working with manufacturing development. Department AA has already started to explore the technology roadmap concept, but need to receive additional support from academia. The respondents are on different hierarchical levels in the organization and this is important to get a holistic view over different stakeholders' perspective of the concept. The respondents provide the researchers' with inputs to all three research sub-questions and *table 4* presents their codes and positions.

Table 4. Respondents at Department AA

Respondent Code	Position
AA1	Manufacturing Technology Manager Verification
AA2	Manufacturing Technology Manager Materials and Heat Treatment
AA3	Manufacturing Technology Manager Components
AA4	Manufacturing Technology Manager Automated Assembly
AA5	Director of Assembly
AA6	Technology Manager Assembly
AA7	Vice President of Manufacturing Engineering
AA8	Manufacturing Technology Specialist Manual Assembly
AA9	Manufacturing Technology Specialist Manual Assembly

4.1.2 Internal Benchmarks

The research project includes two internal benchmarks at company A. These benchmarks provide not only valuable practical experience regarding the execution of the technology roadmapping process in general, but also experiences of maturity assessment for manufacturing technologies in particular. The internal benchmark study delivers inputs mainly to the research sub-questions "What is Technology Roadmap?" and "What is Technology Roadmapping?".

Department AB

Department AB works with product development and has several years of experience regarding technology roadmap. The concept functions as a core activity to find and develop the technologies needed for future products. Empirical material from this department brings important aspects to the research project from a practical experience point of view.

Division AC

While department AA and AB are active within the same division, AC is another division within company A. The division has not embraced the concept of technology roadmap to full extent, however is familiar with the methodology and possesses in depth knowledge about maturity assessment.

The internal benchmark study consists of four interviews and *table 5* presents the participating respondents' codes and positions.

Table 5. Respondents Internal Benchmarks AB & AC

Respondent Code	Position
AB1	Advanced Engineering Technology Leader
AB2	Global Technology Manager
AB3	Director of Manufacturing Research and Advanced Engineering
AC1	Director Global Manufacturing Technology

4.2 External Benchmarks

The external benchmarks at company B and C are similar to the internal benchmarks and provide inputs to the first two research sub-questions.

Company B

Company B is a multinational manufacturing organization with operations in several different business areas. The customer base is widespread across almost 100 countries and the company has production facilities in 28 different countries. It has over 17 500 employees and had revenues of approximately 35 billion SEK in 2014.

Company C

Company C is a global manufacturing company active in 100 countries. It has approximately 140 000 employees in five divisions and had revenues of approximately 300 billion SEK in 2014.

The external benchmark study consists of three interviews and *table 6* presents the respondents' respective codes and positions.

Table 6. Respondents External Benchmarks B & C

Respondent Code	Position
B1	Senior Manager Operations Development
C1	Production Validation Specialist
C2	Global Project Office Manager

4.3 Expert Consultation Company D

Company D is a consultancy firm providing advanced services within product, process, and manufacturing development. Both private companies and public institutions turn to company D for its services. It had revenues of approximately 200 million SEK in 2013. *Table 7* presents the respondent's code and position. The respondent is not aware of the technology roadmap concept in particular, however has a lot of experience regarding manufacturing development in general and therefore provides inputs mainly to the third research sub-question.

Table 7. Respondent Company D

Respondent Code	Position
D1	Operations Development Consultant

4.4 Technology Roadmap

To generate empirical material to the first sub-question "What is Technology Roadmap?" and find out what the concept implies for an organization, the researchers asked the respondents questions regarding the purposes and challenges of technology roadmap. Following sections present the empirical findings regarding technology roadmap's purposes and challenges.

4.4.1 Purposes with Technology Roadmap

The respondents participating in the research project mentioned a number of major purposes with technology roadmap. *Table 8* shows the most frequent purposes and the respondents mentioning them. During the interviews, eight respondents mentioned the importance of creating consensus and understanding regarding both technology roadmap and future technology developments. Nine respondents said the purpose with technology roadmap is to identify necessary activities to bridge the gap between current and future state. Similarly, one recurrent purpose with technology roadmap is that it prepares the organization for the future, which nine respondents mentioned. A majority of the respondents mentioned the purpose to coordinate development activities throughout the organization. The respondents added the strengths of working in a structured way with technology plans for the future and that it enables coordination among different business units.

Table 8. Empirical findings on the purpose of technology roadmap

Purpose of Technology Roadmap	Respondents Mentioning the Purpose
Create consensus in the organization	AA2, AA4, AA5, AA6, B1, AB1, AB2, C1
Identify necessary activities to bridge the gap between current and future state	AA1, AA2, AA3, AA4, AA5, AA7, C2, AA8, AA9
Be prepared for the future	AA2, AA3, AA4, AA6, AB2, C1, AB3, AA8, AA9
Coordinate development activities throughout the organization	AA1, AA4, AA5, B1, AB1, AB2, C1, C2

Respondent AA5 mentioned the opportunity for the organization to focus on and execute fewer activities of higher quality as one of the major purposes with technology roadmap. The same respondent also mentioned that the most valuable part of the concept is the process behind the roadmap, thus social interactions between employees are vital for further developments. Respondent B1 described technology roadmap as a strategic tool to balance and synchronize market pull and technology push. AA1 and AA8 mentioned the technology roadmap's feature of challenging current best practices within manufacturing as one major purpose. Respondent AB1 further described technology roadmap as technology development as a function of time. C1 added the purpose that technology roadmap enables the organization to move in the right direction and ease prioritization among different alternatives. AB3 said that technology roadmap is a tool with the potential to influence top management and the government to perform and prioritize certain activities. Finally, AB2 argued that roadmaps mitigate the risk of sub-optimization and enable the adoption of a holistic view.

4.4.2 Challenges with Technology Roadmap

Technology roadmap has a number of challenges to make it work in an organization. *Table 9* shows the major challenges with technology roadmap. First, ten of the respondents emphasized the challenge to identify the right inputs and competences to develop technology roadmaps. Second, 11 of the respondents added the importance of creating an organizational understanding for technology roadmap and to make the employees understand the purpose and outcome of it. Third, one recurrent challenge according to eight respondents is the difficulty to disaggregate market demands to specific activities, thus the connection between market and manufacturing seldom is perfect. Fourth, to adopt a long-term perspective in the technology roadmap is according to seven respondents a major challenge, as individuals on different hierarchical levels within the organization have dissimilar time perspectives.

Table 9. Empirical findings on challenges with technology roadmap

Challenge with Technology Roadmap	Respondents Mentioning the challenge
Identify the right inputs and competences	AA1, AA3, AA4, AA5, AA6, B1, C1, D1, AA8, AA9
Create an organizational understanding	AA1, AA2, AA3, AA4, AA5, AA6, AA7, B1, C1, C2, AB3
Disaggregate market demands to specific activities	AA2, AA7, B1, AB1, AB2, C1, C2, AA8
Adopt a long-term perspective	AA3, B1, AB2, C1, C2, AA8, AA9

Respondent AA1 mentioned the challenge to make all departments in the organization work with technology roadmap to the same extent, thus there is a risk that some departments fall behind in their endeavors. AA3, AA8, and AA9 highlighted the difficulty to prioritize and execute long-term activities with no immediate consequence as one challenge, thus the organization often prioritizes short-term activities due to shareholders' profit requirements. AA9 also mentioned the issue that technicians often focus on the current processes and relate the goals to these, while management often has a more visionary perspective and puts more attention to the future. AA9 and D1 both mentioned that the solution to this issue might be to break down the long-term vision to concrete goals for the operative organization, as it creates cross-functional consensus regarding the organization's goals.

AA7 mentioned the challenge to converge inputs from a multitude of sites around the world. AA1 said that it is difficult to make the stakeholders provide good inputs to the roadmap development team. C1 implied that it might be difficult to allocate the right competences in the organization, thus many projects often request certain attractive competences simultaneously. Respondent AA5 pronounced the importance and challenge of establishing a transparent communication throughout the organization regarding technology roadmap. AA8 and AA9 highlighted that new work methods demand time, resources, and organizational support to get momentum in the organization. AB1 said it is difficult to break down the work in efficient teams and establish a clear structure and methodology around the concept. AB2 and C1 argued that it is challenging to evaluate the future business potential of a certain technology. In relation to the challenge of organizational understanding, respondent D1 said that high-level managers often do not fully understand concepts like technology roadmaps. The risk is that they do not understand the effects of their decisions.

Respondents AA2, D1, AB3, and AA9 all mentioned the challenge to keep the roadmapping process alive and the roadmap up to date. AA8 added the challenge to properly define the current processes and get access to external information regarding new technologies. Another issue is that the current product portfolio does not allow process standardization across the global manufacturing network, thus the assembly practices in relation to the markets' products are different. Finally, respondent AA8 implied the need of delivering fast results to convince employees that the roadmap concept is an efficient method to use.

4.5 Technology Roadmapping

The following sections provide empirical material to the second research sub-question "What is Technology Roadmapping". The results follow the same structure as the generic roadmapping process in the literature review.

4.5.1 Technology Roadmap Development

The first phase of the roadmapping process includes five sub-stages (prerequisites, current state, future state, strategy, & roadmap report). Subsequent sections provide the empirical material to these sub-stages.

Prerequisites

According to the interviews, there are four main prerequisites for the roadmapping process, which *table 10* presents. First, 11 respondents emphasized the prerequisite to form cross-functional teams with the assignment to develop roadmaps in the organization. For instance, respondent AA9 argued that such teams enable the emergence of differing perspectives and valuable discussions regarding future technological developments. Second, another prerequisite the respondents mentioned frequently is the fundamental principle to develop each roadmap's content on lower hierarchical levels and revise it in a control entity consisting of managers on higher levels. The third main prerequisite during the interviews was the usage of different levels in the roadmap linking together market and technology, thus it enables the organization to balance market events with technological developments in the organization. Fourth, the absolute majority highlighted the importance of a clearly defined time horizon in the roadmap that sets the boundaries for the future technology developments.

Table 10. Empirical findings on prerequisites

Prerequisite for the technology roadmapping process	Respondents mentioning the prerequisite
Cross-functional teams in roadmap development	AA1, AA2, AA4, AA5, AA6, AB1, AB2, C1, D1, AA8, AA9
Roadmap development on lower hierarchical levels and revision on higher levels	AA1, AA2, AA3, AA4, AA7, AB1, AB2, C1, C2, AA8, AA9
Levels in the roadmap linking together market and technology	AA1, AA3, AA4, B1, AB1, AB2, C2, AB3
A defined time horizon for the roadmap	AA1, AA2, AA3, AA4, AA5, AA6, AA7, B1, AB1, AB2, C1, C2, AB3, AA8, AA9

Organization A uses a time horizon of 2-10 years and the reason for excluding the first two years is that this time period only includes short-term development activities and continuous improvements. Respondent AB1 and AB3, which work within advanced engineering, described that they use a 15 years time horizon due to the complexity of developing new technologies. AB2 said that 8-10 years is a suitable time horizon when working with roadmaps, while respondent C2 argued that three years is more reasonable due to the difficultness of predicting the future.

While the majority of the respondents confirmed the fundamental process structure that roadmaps are developed on lower hierarchical levels and then sent upwards, respondent B1 said that they only use roadmaps on a strategic level meaning that lower levels are left out of the roadmapping process. Regarding the composition of the roadmap development team, respondent A8 suggested that technicians should generate the first draft of the roadmap and then pitch it to other functions (e.g. production, maintenance, logistics) to receive their opinions. Based on his previous experience, he argued that brainstorming with several different functions in an early phase often is quite inefficient. However, respondent A9 suggested that the first idea generation session should include other functions than only technicians to get inputs from different expertise areas. The manufacturing technology specialist and the manufacturing technology manager should then sift the ideas to identify the most important to include in the roadmap. D1 added the importance of a heterogeneous team and that it might be necessary to include junior employees in the process with the purpose to challenge senior employees' mindsets.

Respondent AA7 mentioned the importance of anchoring the roadmaps on an organizational level where the managers still have detailed knowledge of specific technologies. Respondent AA8 and AA9 emphasized the need of a roadmap process owner, which is capable of stating demands to lower levels. Respondent AA5 and AA7 added the prerequisite to establish a standardized roadmapping process to ensure that the roadmap efforts are efficient. In addition, AA5 described the roadmapping process according to the following steps:

1. Education of affected employees
2. Brainstorming with local technology specialists and manufacturing engineers
3. Roadmap development including local and manufacturing technology specialists as well as manufacturing engineers
4. Roadmap aggregation to manufacturing technology managers and further upwards in the organization
5. Validation and approval of the roadmap
6. Implementation decisions pushed to each production site

Current State

Table 11 and the subsequent paragraph provide the respondents' methods for defining the current state in the roadmap.

Table 11. Empirical findings on methods for defining the current state

Method to define the current state in the technology roadmap	Respondents mentioning the method
The defined product and process structure	AA1, AA2, AA3, AA4, AA5, AA7, C2, AB3, AA8, AA9
Benchmark and market position	AB1, AB2, C1

The majority of the respondents mentioned that the definition of the current product and process structure is a suitable method for defining the current state. Department AA has a defined manufacturing process based on its current best practices, which is the starting point for all development activities in the organization. Each production facility in the organization should constantly strive towards adapting their manufacturing process to this defined process to ensure a certain degree of standardization in the organization. As the department identifies and develops new best practices, it updates the manufacturing process. Three respondents argued that the current state should be defined based on the organization's performance in relation to other competitors on the market. Respondent AA8 added the importance of defining the current state in the same terms as the vision (e.g. technologies, safety, & environment) to enable gap analysis.

Future State

Table 12 and subsequent paragraphs present four recurrent methods for defining the roadmap's future state. To synchronize the development of roadmaps across several departments, 13 respondents highlighted the principle to break down the corporate vision to department level in order to make it relevant and concrete for each roadmap development team. Seven respondents from the manufacturing development department AA expressed the vitality of dividing the vision into a number of focus areas, such as safety, environment, costs, productivity, and new products or processes. The respondents disagreed regarding the usage of multiple scenarios for the future, thus only three respondents argued it is necessary. Six respondents mentioned the involvement of external actors to define the future state as necessary.

Table 12. Empirical findings on future state definition

Method to define the future state for the technology roadmap	Respondents mentioning the method
Broken down from top management	AA1, AA2, AA5, AA6, AA7, B1, AB1, AB2, C2, D1, AB3, AA8, AA9
Divided and expressed in multiple specific key areas (e.g. safety, environment, costs)	AA1, AA3, AA4, AA5, AA6, AA8, AA9
Use multiple alternative future states	AA6, C1, AB3
Use external influences to define the future state	AA5, AA7, C2, AB3, AA8, AA9

Respondent AA2 and AA9 said that there has to be a clearly defined future state to avoid the risk of misinterpretation, thus it enables all business units to strive towards a common goal. D1, AB1, and AA8 described the importance of breaking down the future state to specific activities to create an organizational understanding for how certain activities contribute to the fulfillment of the future state. AA4 and AA5 put emphasis on the importance of setting up an ambitious future state to challenge the organization. AA6 argued that safety and environment are the two most important factors for manufacturing to consider when the future state is defined. AA6, C1, and AB3 argued there is a need to work with scenarios and alternative futures, thus the future is hard to predict. AB3 added the need to apply probabilities to these scenarios to direct efforts more efficiently, however C1 argued that it is difficult to apply probabilities to scenarios and suggested to rely on gut feeling instead.

Alternative ways of getting access to inputs from the external environment were universities (AA7, AA5, AB3, AA8, AA9), suppliers (AA9), competitors (C2, AB3, AA9), conferences (AB3), and fairs (AA1, AA4, AA8, AA9). Further, C2, AB3, AA8, and AA9 mentioned that they use dedicated internal departments to scan the external environment.

Respondent AB3 described a process that breaks down market trends to specific activities through the following four steps:

1. Identification of megatrends and forecasts of the market
2. Analysis of the business implications of the factors in the previous step
3. Consider product development, thus product should be an input to manufacturing development
4. Define the directions for the upcoming roadmap development

Strategy

The respondents confirmed the methods for generating the strategy in the technology roadmap to varying degrees and *table 13* and upcoming paragraphs present the respondents' opinions regarding these methods.

Table 13. Empirical findings on strategy

Method to generate the strategy	**Respondents mentioning the method**
Activity identification through backcasting	AA3, AA4, AA5, AA7, AB1, C2, D1, AB3, AA8
Activity identification through forward planning	AA1, AA2, AA5, AA7, B1, AB2, AA8, AA9
Parallel tracks	AA3, AA7, B1, AB1, AB2, C2, D1, AB3, AA9
Maturity assessment	AA1, AA2, AA3, AA4, AA5, AA7, B1, AB1, AB2, C1, D1, AB3, AC1, AA9
Risk management	AA1, AA2, AA3, AA4, AA5, AA7, B1, AB1, AB2, C1, C2, D1, AB3, AA8, AA9

There are some differences regarding the respondents' preferences on how to map up the activities to reach the future state. A small majority argues backcasting is preferable when defining the strategy. AA4 and C2 explained that it might be difficult to think visionary with the current state as starting point, and therefore suggested backcasting. On the other hand, AA2 argued that it is vital to start from the current state when defining the strategy, thus it sets the boundaries for what is possible to do in the future. AA5, AA7, and AA8 emphasized the importance of balancing forward planning and backcasting, thus forward planning considers short-term continuous improvements, while backcasting is more long-term focused.

The respondents had different opinions regarding the use of parallel technology tracks in the roadmap. AA3 described that the use of parallel tracks is necessary as it lets the organization to start development activities without a clear picture of the future. AA4, on the other hand, added the difficultness of having parallel tracks due to resource limitations, which means that technology trajectories need to be decided upon before anything is done in practice. AB1 added the importance of having several options available to a certain point in time when it is necessary to make a decision. Additionally, AB3 argued that it is impossible to make final decisions regarding the trajectory for the upcoming 15 years and that it is vital to have several alternatives.

Regarding maturity assessment, both TRL and MRL have been encountered during the interviews. AA1, AA2, AA3, and AB1 mentioned TRL as a proper maturity assessment model, while D1, AB3, and AC1 advocated for the MRL model. Respondent AC1 implied that MRL takes a broader perspective than TRL, thus many different aspects are included (e.g. logistics & work environment). MRL forces the developers to ask questions from a manufacturing development perspective while TRL is more focused on product development. However, the MRL scale should not be seen as a perfect truth and instead work as a checklist of vital factors to consider, according to AC1. AA4 suggested benchmarks and pilot projects as methods to assess the maturity of a certain technology. B1 mentioned prototype testing as a way to verify technology maturity. AA9 said that the use of external experts is a suitable method to verify the maturity of a specific technology.

Various standard risk evaluation frameworks assessing risks' probability and impact facilitate risk management in the roadmap development phase, according to the respondents AA1, AA2, AA3, AA4, C1, C2, AB3, and AA8. AA5 said the technology roadmap itself mitigates risks, thus it enables the organization to be aware of the risks it is facing. Respondent AA9 explained that targets should be realistic and achievable in order to mitigate risks. AB1 said that risk analysis is included in the maturity assessment model TRL. AA7 argued that the use of superior pilot sites in the manufacturing system is a way to mitigate risks, thus advanced competences and large resources at these sites facilitate risk identification and mitigation.

Respondent AB3 suggested a process, which facilitates strategy definition and identification of necessary activities:

1. Relate the vision to the current state and perform a gap analysis
2. Use backcasting to fill the gap between the current state and the vision
3. Find a balance between technology push and technology pull
4. Use a maturity assessment model on each technology in the roadmap

Roadmap Report

Table 14 provides the factors necessary to include in the roadmap report. The term activity list is a frequently recurring explanation on what the roadmap report should include, thus 14 respondents mentioned it. For instance, AA3 described it as a prioritized activity list, which enables managers to make decisions regarding which technology development projects to pursue with in the future. AB1 described the report as a description of proposed technology developments as a function of time. The second most frequently mentioned factor to include in the roadmap report is a detailed description of each project's resource requirements.

Table 14. Empirical findings on roadmap report

Information to include in the technology roadmap	Respondents mentioning the information
Activity list to bridge the gap between current and future state	AA1, AA2, AA3, AA4, AA6, AA7, B1, AB1, AB2, C1, C2, AB3, AA8, AA9
Resource requirements	AA1, AA2, AA3, AA4, AA7, AB1, AB3

AA2 and AA4 mentioned the need to achieve a clear documentation in connection to the roadmap, which includes detailed descriptions of resource, competence, and time requirements. According to AA1, the roadmap report should include specified targets and associated activities with underlying documents considering resource and time requirements. AA2 mentioned that the roadmap should explain the gap between current and future state and an activity plan to balance market demands and technology developments. Respondent AA7 argued that the roadmap report should include a detailed description of each activity's purpose, time plan, and eventual result. AA4 added the need to include a description regarding the business case of each activity to motivate its relevance.

4.5.2 Technology Roadmap Follow-up

The second phase in the roadmapping process includes the sub-stages roadmap validation and roadmap review, and following sections present these sub-stages' respective empirical material.

Roadmap Validation

Table 15 presents the respondents' answers regarding how to validate the roadmap. First, 13 of the respondents emphasized the need for a control entity that scrutinizes the roadmap content. Second, ten respondents argued the prioritization of different roadmaps to enable progression with only the most promising ones as a vital activity. Third, seven of the respondents described the importance of ensuring a certain level of quality in the roadmapping process.

Table 15. Empirical findings on roadmap validation

Method to validate the technology roadmap	Respondents mentioning the method
Control entity to scrutinize roadmap content	AA1, AA2, AA3, AA4, AA5, AA6, AA7, AB1, AB2, C1, AB3, AA8, AA9
Prioritization of different roadmaps	AA1, AA2, AA3, AA4, AA5, AA6, AA7, AB2, C1, AB3
Quality assurance	AA2, AA3, AA4, B1, C1, AB3, AA9

In department AA, a control entity consisting of both local and global manufacturing technology managers is responsible for the validation of roadmaps developed on lower levels. Each manufacturing technology manager is responsible for gathering the roadmaps for its technology area and sending them upwards in the organization after validation. However, respondent AA6 mentioned that it might be necessary to include different key stakeholders in the control entity to get a more holistic perspective on the issues dealt with in the roadmap. AB2 said that they include various support functions (e.g. finance) to strengthen the holistic perspective. C2 argued that top management should set the overall goals and then rely on the organization's capability to fulfill these goals, which means that top management should not be involved in details. Respondent AA9 added the importance of having technology managers with practical experience within the specific area of expertise to ensure quality. AA9 also implied that the control entity should consist of people from different industries to further validate the roadmap content.

The roadmaps' potential to meet stated demands should be the base for prioritization, according to respondent AA3, AA6, AA7, and AB3. In a similar sense, AA1 and AA5 mentioned benefits and costs for each activity as factors to consider when prioritizing among roadmaps. AA4 and AB2 pronounced the necessity to base prioritization on the roadmap's business case.

The fundamental principle to ensure high quality roadmaps is, according to AA2, AA3, C1, and AB3, to assign the right competences to work with the concept, both in the roadmap development and in the entity controlling the roadmap from lower organizational levels. Respondent AA4 suggested that constantly challenging the employees in the roadmap development phase is a way to ensure high quality.

Roadmap Review

Table 16 and the following paragraphs introduce the respondents' opinions regarding the revision of the roadmap.

Table 16. Empirical findings on roadmap review

Method to review the technology roadmap	Respondents mentioning the method
A predefined interval for roadmap revision	AA1, AA2, AA3, AA4, AA5, AA6, AA7, B1, AB1, AB2, C1, C2, AB3, AA8, AA9
Regular reconciliation meetings	AA1, AA2, AA5, AA6, AA7, B1, AB1, AB2, C1, C2, AB3, AA8, AA9

The absolute majority of the respondents pronounced the importance of a predefined time interval for roadmap revision, however there where some differences regarding the length of this interval. Respondents AA1, AA5, AA7, AB1, AB2, C1, and C2 suggested that one revision per year is suitable. However, AA2, AA3, AA4, AA6, B1, and AB3 argued there is a need to revise the roadmaps in shorter intervals. One recurrent feature in the interviews was that it is important to keep the roadmap alive during the year through regular reconciliation meetings. AA8 argued the revision interval depends upon the time horizon, thus short-term activities require shorter intervals and long-term activities demand longer intervals. AA2 said there is a risk that the budget steers the roadmap too much in case of yearly revisions. AA3 and AA9 added the importance of balancing momentum and work load, meaning that too short revision intervals create too much work for the organization while too long intervals are harmful for the roadmap's momentum. C2 mentioned that their organization tried half-year revisions and that it created too much work, which led to a change of interval length to once a year. AB2 highlighted the necessity to have an event-based roadmap, which means that the organization updates the roadmap with new content when a new vital circumstance emerges. AB3 suggested one larger revision per year where new projects are added and one smaller revision per year where a suggestion list is considered and projects only are added if critical.

One recurrent discussion topic during the interviews was whether or not to use progress indicators in the roadmap. Respondents AA4 and AA7 advocated for the use of indicators and implied that they are necessary to keep track of the development activities in the organization. However, AA6 mentioned that it is not interesting to measure facts or results for a visionary tool such as technology roadmap. AA5 argued there is no point in measuring qualified guesses and AB2 meant that it is difficult to measure efficiency on future developments and on something that is not recurrent. AB2 also added that it is possible to measure afterwards if the organization reached the goals, however it is misleading due to regular revisions and updates of the roadmap.

4.6 Important factors related to manufacturing

The third and final research question "Which factors related to manufacturing need to be considered in Technology Roadmapping?" are the focus of subsequent paragraphs and *table 17* presents the most important factors according to the respondents' previous manufacturing development experiences. Seven respondents emphasized the vitality in having a long-term focus and a deliberate strategy to ensure future success. This enables the organization to, for instance, plan the factory layout (AA4) and prepare manufacturing processes on future products and volumes (AA7). It is also important to be prepared and have "on-the-shelf" solutions to industrialize at the time of new product launches. This is, according to AA3, a way to ensure improvement of manufacturing technologies over time. It enables the organization to be proactive instead of only focusing on short-term "fire fighting" activities. Another issue is to consider the product development department when developing new manufacturing technologies. This relates to that product development often functions as input to manufacturing development due to its direct relation to the market (AA1 & AA6). Implementation of new technologies in manufacturing often demands long lead-times, which six respondents argued is important to consider in order to successfully develop and implement new manufacturing technologies.

Table 17. Empirical findings on manufacturing preparation

Factor to consider related to manufacturing	Respondents mentioning the factor
Long-term focus and have a clear strategy for the future	AA2, AA4, AA6, AA7, D1, AA8, AA9
To be proactive and to have on the shelf-solutions	AA3, AA4, AA6, AA8
Product as input to manufacturing development	AA1, AA3, AA6, AB2, C1, AB3, AA8, AA9
Long lead-times in manufacturing development	AA3, AA6, AB1, AB2, C1, AB3

Respondent AA1 and AA2 mentioned the importance of having a holistic view as the organization has manufacturing plants all over the world, which implies that every plant's problems require consideration. AA1 further described that it is vital to define the current manufacturing process to have a good starting point. Respondent AA4, AA8, and AA9 argued the importance of considering flexibility in factory layout. AA6 added safety and productivity, where safety is the key factor in all manufacturing.

Respondent D1 and AA8 put emphasis on the link between market and manufacturing and that it needs to be a red thread going through strategic, tactical, and operative levels. The operators need to have an understanding of strategic issues, while management must understand the operative issues. D1 added that solutions in manufacturing should be intuitive, it need to be easy to understand how to execute manufacturing activities.

Respondent AA1 said that product development gets direct inputs from the market and that manufacturing development, in turn, gets inputs from product development. This might be problematic and challenging according to respondent AA6, AB1, C1, and AB3, thus process development often gets involved too late in the process and has to make fast adaptions to the manufacturing processes. Another factor that makes this aspect even more problematic, according to AA3 and AB1, is that manufacturing development often requires longer lead-times than product development. AA8 added that late changes from product development have caused large consequences for manufacturing development in the past. AA6, C1, AB3, and AA8 mentioned the necessity of involving manufacturing development earlier. The reason to involve manufacturing development earlier is according to these respondents to challenge product development to consider manufacturing to a greater degree in its development activities. In other words, it is vital to let manufacturing influence the product to increase manufacturability.

Another important factor mentioned by AA4, AA6, AA7, and AB3 is that manufacturing development needs to consider a wide array of inputs, such as safety, product, work environment, costs, environment, production output, and factory layout. AA8 mentioned that manufacturing development has to deal with the people working in manufacturing and tackle challenges coupled with organizational change. It is therefore vital to motivate why certain changes should take place in manufacturing to convince the operators and other employees. AA8 added that the establishment of organizational maturity is a key factor to make the roadmapping process work properly. AA7 mentioned that the product development department AB only has to consider the development of new products, while the manufacturing department AA has two main responsibilities, both manufacturing itself and manufacturing development. He emphasized that this might become problematic as department AA has to take both every day manufacturing issues and future developments into consideration. It is often the case that short-term productivity goals get the highest priority, while long-term development activities get lower priorities. Respondent AA8 implied that management tends to have a more long-term strategic view, while the specialists on lower levels have to balance short and long-term perspectives. AA8 further argued that short-term activities often tend to get the highest priority to keep production going.

The absolute majority of the respondents (AA2, AA3, AA4, AA5, AA6, AA7, AB1, AB2, C2, D1, & AB3) argued that it is possible to use similar work practices in manufacturing and product development regarding technology roadmap. D1 said that each workstation in manufacturing could be seen as a product, meaning that it is possible to use the same methods. AA3 and AA7 implied that the same work practices around technology roadmap should be used in both manufacturing and product development to achieve standardization in the organization.

5 Analysis

The analysis compares theories from the literature review with the respondents' practical experiences and opinions. The analysis follows the same structure as the literature review and the empirical findings.

5.1 Technology Roadmap

An analysis of the purposes and challenges with technology roadmap follows in subsequent sections, which provide inputs to the first research sub-question "What is Technology Roadmap?". *Figure 16* presents the main findings on the purpose and challenges with technology roadmap.

What is Technology Roadmap?

- Creates organizational consensus regarding future technology developments
- Enables the organization to go from the current state to a desirable future state through the identification of necessary technology development activities
- Facilitates cross-functional coordination and communication of technology development activities
- Vital to identify and include the right inputs and competences to ensure high quality roadmaps
- Dependent on support from the organization in general and top management in particular
- Balances long-term technology development activities and short-term improvements

Figure 16. Main findings on the first research sub-question, "What is Technology Roadmap?"

5.1.1 Purposes with Technology Roadmap

There are several purposes for companies to work with technology roadmap. The literature presents multiple reasons for utilizing technology roadmaps and the following paragraphs compare these with the results from the empirical findings.

According to the interviews, one recurrent purpose with technology roadmap is to reach consensus about where the organization should position itself in the future. The majority of the respondents considered consensus extremely important in order to have a common view of future investments. This is congruent with Simonse, Hultink, and Buijs (2014) who claim that one of the main benefits with technology roadmap is to prioritize and make required investments in the right time to stay competitive in the market. Respondent AA5 mentioned the main purpose with technology roadmap is not the roadmap itself, but instead the process behind the concept and the social interactions among employees. Phaal and Muller (2009) also mentioned that the social interactions among employees to reach consensus about the future often is more valuable than the actual roadmap.

Nine respondents clearly addressed how technology roadmap eases identification of necessary activities to bridge the gap between current and future state. Respondents C1 and AB3 described that technology roadmap enables the organization to move in the right direction and the defined future state is an important support when prioritizing among different alternatives for reaching the future state. There is clearly a match between what the respondents consider the purpose with technology roadmap and what the literature advocates. Phaal, Farrukh, and Probert (2005), Daim and Oliver (2008), Kostoff and Schaller (2001), and Simonse, Hultink, and Buijs (2014) illuminate that technology roadmap is a way to define possible trajectories between the current and future state.

According to Kerr, Phaal, and Probert (2011), technology roadmap is not only a communication tool, but also a way to ease coordination of activities throughout the whole organization. Eight respondents mentioned that one of the main purposes with technology roadmap is to coordinate development activities across the organization, which indicates a match between the literature review and empirical findings.

5.1.2 Challenges with Technology Roadmap

The literature review and empirical findings have both identified a number of challenges with technology roadmap. These challenges enable the researchers to build a comprehensive picture of the technology roadmap concept and its implications for an organization.

Ten respondents mentioned the difficulty and challenge in identifying the right inputs and competences to ensure a high quality roadmap. For instance, respondent AA1 mentioned the challenge to make the stakeholders generate and deliver inputs to the team responsible for roadmap development. This is particularly difficult when different departments in the organization are on different levels in their roadmap endeavors. AA7 nuanced the discussion with the implication that it is challenging to converge and coordinate inputs from production sites scattered all over the world. Phaal, Farrukh, and Probert (2005) also present the challenge to generate and deliver good inputs to the roadmap, thus the overall quality of the roadmap is dependent upon its inputs. C1 further emphasized the vitality of identifying and allocating the right competences to participate in a particular activity, which might be challenging due to shortages of individuals in certain expertise areas. Jeffrey, Sedwick, and Robinson (2013) and Kostoff and Schaller (2001) also mention the aspect of involving the right competences in the roadmap development. Hence, it is rather safe to say that it is a major challenge to provide the roadmapping process with good inputs and competences, thus the whole roadmap depends upon these factors.

Another challenge mentioned by the majority of the respondents is to create a strong organizational understanding and support for technology roadmap. Respondent AA8 and AA9 both mentioned that new work practices require support from the organization and top management to get momentum. Related to this is AA5's argument that transparent communication across the organization is a challenge, however if done properly it can stimulate organizational understanding. Similarly, AA8 suggested that the delivery of fast results from the roadmap is a way to communicate the benefits of using the tool in the organization. It is apparent that management plays a central role in the creation of organizational understanding for the technology roadmap concept, however D1 argued that top management often does not fully understand the implications of concepts like technology roadmap. Hence, organizational understanding is required across both functional borders and hierarchical levels. Kostoff and Schaller (2001) mention commitment from senior management as a vital factor behind the success of the technology roadmap concept in an organization. Consequently, both the literature and empirical findings highlight the importance of organizational understanding and support for technology roadmap.

There is a small difference between the literature review and the empirical findings in the issue of disaggregating market demands to technology development activities. In the literature, it is often stated that market demands and trends have to be disaggregated to technology development activities (e.g. Phaal, Farrukh, & Probert, 2005; Kerr, Phaal, & Probert, 2011), however it is not mentioned that this might be one of the greatest challenges with technology roadmap. Eight respondents argued that the translation of future market trends to specific technologies is complex, thus everything regarding the future is difficult to predict. The challenge of disaggregation is one feature of the technology roadmap concept that is vital to consider and the organization has to find methods to resolve this issue.

One similarity between the literature and the interviews was the issue of balancing long-term and short-term activities. Simonse, Hultink, and Buijs (2014) mention this balance as a success factor for the technology roadmap concept. However, according to seven respondents is this balance a major challenge to overcome. AA3, AA8, and AA9 said that it might be difficult to prioritize long-term activities with no short-term effect, thus solving short-term issues is more attractive in a shareholder point of view and therefore gets the highest priority. AA9 implied that technicians often have a shorter time perspective than top management, which is more visionary and has a longer time perspective. Prioritization of long-term activities and time perspective clashes between different hierarchical levels might very well be two challenges to take into consideration in order to make the technology roadmap endeavors efficient.

5.2 Technology Roadmapping

The following sections present the analysis of the technology roadmapping process in terms of similarities and differences between theory and practice. The sections relate to the second research sub-question "What is Technology Roadmapping?" and follow the process structure presented in the literature review. *Figure 17* shows the main findings on technology roadmapping.

What is Technology Roadmapping?

- An iterative process with the two major phases technology roadmap development and technology roadmap follow-up
- A prerequisite to have heterogeneous teams in roadmap development
- A definition of current "best practice" manufacturing processes forms the current state in the roadmap
- The roadmap's future state has to be broken down from top management
- Unclear if it is necessary to define multiple future states
- Balance forward planning and backcasting to include both short-term improvements and long-term technology development
- Maturity assessment through MRL is appropriate in manufacturing development
- The roadmap report communicates an activity list to close the gap between the current and future state and the associated resource requirements
- A control entity validates and prioritizes the roadmaps to ensure high quality
- Roadmap review in a defined time interval, which balances momentum and workload
- Regular reconciliation meetings to keep track of the progress of technology development activities

Figure 17. Main findings on the second research sub-question, "What is Technology Roadmapping?"

The technology roadmapping process based on existing literature consists of two main phases, which together facilitate both the development of the roadmap content and follow-up by key stakeholders. These phases form an iterative cycle in which the roadmap is developed and followed-up in predefined time intervals. Respondent AA5 and AB3 described their respective roadmapping processes, which seem to be quite similar to the roadmapping process described in the literature and include the same fundamental phases where the roadmaps are developed on lower hierarchical levels and followed-up on higher levels. The fact that both department AA and AB work according to such processes indicates that there are no fundamental differences between technology roadmapping for product development and manufacturing development. AB3 mentioned two sub-stages that together identify important market trends and business implications as well as the specific development activities required to generate the roadmap content. These sub-stages are very similar to the process presented by Vishnevskiy, Karasev, and Meissner (2015) including foresighting and roadmap development.

The literature on technology roadmapping seem to be quite accurate in comparison with how organizations work with the concept in reality and the fundamentals in the technology roadmapping process presented in the literature are therefore assumed to be valid.

5.2.1 Phase 1: Technology Roadmap Development

The researchers asked the respondents questions regarding the first phase's five sub-stages prerequisites, current state, future state, strategy, and roadmap report. The comparison of theory and practice related to these sub-stages is the topic in following sections.

Sub-stage 1: Prerequisites

Regarding prerequisites to the technology roadmapping process, the majority of the respondents mentioned cross-functional teams as a critical factor. The inclusion of several different competences and perspectives is vital to develop a qualitative roadmap, according to these respondents. Additionally, respondent D1 emphasized the importance of heterogeneous teams in general, and the inclusion of both senior and junior employees in particular. Junior employees often have a more creative approach and open mind-set compared to their senior colleagues, which on the other hand have more practical experience. A healthy mix of junior and senior employees might be one ingredient to develop high quality roadmaps. Respondent AA9 further mentioned the benefit of including multiple expertise areas in the initial brainstorming session thus it enables the emergence of several different suggestions and ideas, which in the next stage can be sifted and condensed by a smaller team. Yamashita, Nakamori, and Wierzbicki (2009) imply that the social interaction between individuals in the roadmapping process is one main benefit with the concept in general. Further, several additional articles (e.g. Garcia & Bray, 1997; Kostoff & Schaller, 2001; Kerr, Phaal & Probert, 2011; Strauss & Radnor, 2004) also emphasize the necessity to consider the team composition in order to maximize the chances of success, which confirms the correspondence between theory and practice.

A couple of prerequisites relate to the context in which the technology roadmap is applied. The literature (e.g. Garcia & Bray, 1997; Phaal & Muller, 2009; Phaal, Farrukh, & Probert, 2005; Phaal, Farrukh, & Probert, 2004; Yamashita, Nakamori, & Wierzbicki, 2009) highlights the issues of defining specific technology areas, choosing a suitable time horizon, constructing the graphical design of the roadmap, defining the roadmap layers, and standardizing the roadmapping process and its connections to other organizational routines and structures. The majority of the respondents participating in the research project confirmed the need to have a defined time horizon, a standardized and anchored work practice around the roadmap, and articulated layers in the roadmap. AA7 added the necessity to anchor the roadmaps on a hierarchical level where the managers still have detailed knowledge about specific technologies. To make the roadmap efforts efficient, respondent AA8 and AA9 suggested that a roadmapping process owner is required, which has knowledge about both the process itself, the affected stakeholders, and their demands. Kostoff and Schaller (2001) also argue the necessity to assign one individual the role as technology roadmapping process owner. Consequently, there are many similarities between the literature and the interviews regarding these prerequisites.

Sub-stage 2: Current State

One vital activity when working with technology roadmap is to define the current state and highlight the contemporary conditions for the organization (Phaal, Farrukh, & Probert, 2005;

Hasse, Birke, & Schwarz, 2012; Garcia & Bray, 1997). However, the literature does not mention how the current state should be defined, only that it is an important activity to conduct before establishing the future state. During the interviews, the majority of the respondents considered a well-defined current state as an important starting point. Ten respondents mentioned that the current product and process structure form the organization's current state, while three respondents illuminated that benchmarks against other companies and current market position is a suitable methodology. An appropriate method to define the current state in manufacturing is department AA's approach to define the current best practice manufacturing process, which is continuously updated after the development and implementation of new manufacturing technologies at the pilot sites.

Sub-stage 3: Future State

A clear future state is crucial in order to steer the organization in the right direction (Hasse, Birke, & Schwarz, 2012; Garcia & Bray, 1997; Phaal, Farrukh, & Probert, 2005). The majority of the respondents considered a well-defined future state broken down from top management to be vital when working with technology roadmaps. Respondent AA2 and AA9 added that a clear future state from top management reduces the risk of misinterpretation and enables all business units to strive towards a common goal. Seven respondents also mentioned the importance of translating the corporate vision to a level that clearly communicates the implications for each department. These respondents argued the necessity of making the future state possible to understand and relate to by dividing it into specific key areas (e.g. safety, environment, and costs).

Trying to predict the future is obviously difficult and the establishment of several future states or scenarios might help reducing the risk of ending up on the wrong path (Saritas & Aylen, 2010). Respondents AA6, C1, and AB3 all argue that alternative futures are necessary, thus it is difficult to perfectly predict the future. However, the majority of the respondents believed that it is more applicable to have one defined future state to decrease complexity.

Six respondents mentioned external influences as an important input to define the future state. Channels to get access to external information were universities, fairs, conferences, suppliers, and competitors. Additionally, respondents C2, AB3, AA8, and AA9 described that they use an internal department with the task to scan the external environment to grasp new information. Karasev and Vishnevskiy (2013) and Phaal and Muller (2009) emphasize that external actors play a crucial role when defining the future state. This clearly depicts the importance of interacting with external actors, thus the employees within the organization may not possess the information and knowledge needed to create a reasonable picture of the future.

Sub-stage 4: Strategy

Existing literature (e.g. Arnold et al., 2010; Karasev & Vishnevskiy, 2013; Hasse, Birke, & Schwarz, 2012) advocates that backcasting is the most appropriate method to identify activities to bridge the gap between current and future state. However, the respondents' answers regarding activity identification varied, thus nine suggested backcasting and eight argued forward planning as the most appropriate method for activity identification. None of the articles in the literature review suggested forward planning as a suitable method to identify activities. Respondent AA4 and C2 favored backcasting and implied that it is difficult to have a visionary approach in forward planning, thus it is easy to limit yourself to the current processes. On the contrary, AA2's argued that it is vital to start from the current state as it sets the boundaries for what is possible to do in the future. AA5, AA7, and AA8 suggested that it is a good idea to balance backcasting and forward planning, as it enables the organization to synchronize short-term continuous improvements and long-term visionary ideas. Hence, both backcasting and forward planning are important to consider when the roadmap is developed, however it might be necessary to find a way to separate short-term continuous improvements activities from the long-term development activities.

Even though Garcia and Bray (1997) argue it is preferable to run technology development activities in parallel and have several alternatives active simultaneously, the respondents had varying opinions regarding this aspect. For instance, AA4 mentioned that resource limitations restrict the organization's capability to have several alternatives active at the same time, which implies that the final decision regarding the path to follow is necessary before anything is done in practice. Respondent AB1 and AB3 strongly suggested that it is vital to use parallel tracks for the reason that the future is next to impossible to predict, which means that the organization has to find a way to safeguard itself against these uncertainties.

TRL (Greitemann et al., 2014) and MRL (Department of Defense, 2011) are methods facilitating technology maturity assessment. The respondents AA1, AA2, AA3, and AB1 suggested TRL, while D1, AB3, and AC1 advocated MRL. The results of this research project indicate the MRL scale is more suitable than TRL to assess the maturity of manufacturing technologies, as TRL does not consider manufacturability. For instance, AC1 argued the MRL scale takes a broader perspective than TRL and include all factors important to consider in manufacturing, however the scale still needs to be customized to fit in the organization and should not be seen as a perfect truth.

Ilevbare, Probert, and Phaal (2014) emphasize the importance of risk aware roadmapping, which implies risk identification, assessment, and treatment for each activity in the roadmap. This was confirmed by respondent AA1, AA2, AA3, AA4, C1, C2, AB3, and AA8, which all suggested that risk management is done on project basis with methods centered around a certain risk's probability and impact. AA5 suggested that the roadmap itself is a tool for risk management, thus it in its very nature makes the organization aware of the risks it faces. Respondent AA7 further suggested that the use of pilot sites is an appropriate method to mitigate risks, thus only a small part of the organization initially exposes itself to the risks inherent in a new manufacturing technology. AA7 also added that superior resources and competences at these pilot sites enable them to manage the risks emerging with a new technology.

Sub-stage 5: Roadmap Report

The roadmap report is a document that provides the management team with a detailed plan of further actions needed to implement the roadmap activities and reach the future state

(Vishnevskiy, Karasev, & Meissner, 2015; Hasse, Birke, & Schwarz, 2012). The purpose is to deliver a carefully considered technology roadmap report, which should support managers in their decision-making process (Phaal & Muller, 2009; Yamashita, Nakamori, & Wierzbicki, 2009). Garcia and Bray (1997) describe the importance of a well defined report with a clear message to increase the ability for managers to make the best possible prioritizations based on the information given in the roadmap.

Thus several roadmap reports will be aggregated to the management team, each technology in the roadmap should be defined from its current status, development time, resource requirements, and implementation plan (Garcia & Bray, 1997; Kostoff & Schaller, 2001). During the interviews, 14 respondents mentioned the roadmap report should consist of an activity list, aiming at a detailed description of how to close the gap between the current and future state. The respondents' answers are congruent with the literature, thus the roadmap report should enable managers to make decisions on this type of information. Additionally, seven of the respondents considered resource requirements vital to highlight the practical aspects of what is possible to achieve in the organization. This also indicates the importance of delivering a roadmap report with a detailed description of necessary resources to fulfill the implementation plan. Respondent AA1 further illuminated the roadmap report should not only consider resource requirements, but also a defined schedule over when these resources should be available. Respondent AA4 emphasized the need of relating the content in the roadmap report to each activity's business case in order to ease prioritization.

5.2.2 Phase 2: Technology Roadmap Follow-up

The second phase in the technology roadmapping process is roadmap follow-up, which includes the two sub-stages roadmap validation and roadmap review. The analysis of the literature review and empirical findings regarding these sub-stages follows in the upcoming sections.

Sub-stage 1: Roadmap Validation

It is necessary for managers to validate the roadmap before the development of an implementation plan. The group that validates should possess the authority to approve or reject the roadmap (Garcia & Bray, 1997). The majority of the respondents described a need for a control entity that evaluates and scrutinizes the different roadmaps' contents to keep high quality of the delivered roadmaps. Respondent AA9 argued the control entity should consist of people with practical experience within the specific technology area to ensure high quality decisions. Respondent AB2 and AA9 suggested that people from different industries and functional areas could strengthen the holistic view of the control entity. Daim and Oliver (2008) depict the importance of prioritization among different roadmaps due to resource constraints. There are similarities between the literature and empirical findings, thus ten respondents argued that prioritization among roadmaps on management level is necessary to find the most promising alternatives for the future.

Sub-stage 2: Roadmap Review

Garcia and Bray (1997) suggest that the organization's normal planning cycle should decide the length of the interval for roadmap review. On the other hand, Daim and Oliver (2008) suggest revision on quarterly or annual basis. The majority of the respondents mentioned the need for a predefined interval for roadmap revision. However, the suggested length of the interval differs between the respondents. Seven respondents considered revision once a year to be suitable, mainly due to resource and time constraints. Six respondents argued for shorter intervals to keep momentum in the concept. Respondent AA2 said that yearly intervals create a risk that the budget steers the roadmap development too much. C2 described how their organization have tried half year revisions, but with the result of too much workload for the people developing the roadmaps. AA3 and AA9 discussed the importance of balancing the workload. Short revision intervals might result in too much of a burden, while too long time intervals might result in loss of momentum. Respondent AB3 added to this discussion the possibility to have one small revision and one large revision per year. In the small revision, new ideas should be appointed to a suggestion list and in the large revision, new projects should be added to the roadmap. The answers from the respondents clearly depict pros and cons with short and long time intervals, however do not deliver any clear results regarding which interval length is most suitable.

Arnold et al. (2010) advocates for the use of a navigation board with the responsibility to monitor the progress of the development activities in the roadmap. This board is rather similar to the formation of individuals in department AA that has regular reconciliation meetings regarding the progress of the activities in the roadmap. Department AB, company B, and company C use similar methods to monitor progress. Moreover, Arnold et al. (2010) suggest that some predefined indicators should monitor the overall progress of the roadmap, however this aspect was something the respondents had differing opinions on. AA4 and AA7 favored the use of progress indicators, as it enables the organization to keep track of its development activities. On the other hand, respondent AA6, AA5, and AB2 argued against the use of such indicators. For instance, AA5 meant that there is no point in measuring qualified guesses, which basically is the essence of technology roadmap thus nothing regarding the future is completely certain. A conclusion is that the use of regular reconciliation meetings with discussions of various topics in the roadmap is an appropriate way to keep track of the development activities. Whether or not performance indicators are appropriate is although unclear according to the results of this research project.

5.3 Important Factors related to Manufacturing

The analysis of the third and final research sub-question “Which factors related to manufacturing need to be considered in technology roadmapping?” is the topic of the subsequent section. *Figure 18* presents the main findings to this question.

Which factors related to manufacturing need to be considered in Technology Roadmapping?

- Manufacturing development requires long lead-times and a proactive approach
- Necessary to have "on-the-shelf" solutions to be prepared on future product launches
- State demands to product development to ensure product manufacturability
- Important to prioritize long-term technology developments with no immediate consequences
- Manufacturing's primary responsibility is to manufacture the products while technology development is a secondary assignment
- Manufacturing development needs to consider a multitude of different stakeholders and factors (e.g. employees, safety, productivity, work environment)

Figure 18. Main findings on the third research sub-question, "Which factors related to manufacturing need to be considered in technology roadmapping?"

One of the most important factors to consider in manufacturing development is, according to six respondents, the long lead-time any changes in manufacturing require that potentially creates problems when the company introduces new products. The solution to this problem lies to some degree in the respondents' additional factors to consider in manufacturing, thus a long-term focus and a clear strategy enable the organization to prepare itself for future factory layout requirements (AA4) and product launches (AA7). Nyhuis et al. (2010) also stresses the need to consider factory layout in an early stage. The importance of having technology solutions "on-the-shelf" (e.g. AA3) also relates to the issue of long-lead times for process changes, as it lets the organization to start technology development projects with no immediate plan for industrialization in advance of new product launches. When the time for product launch eventually comes, the manufacturing development department can industrialize these "on-the-shelf" solutions and hence reduce the lead-time (AA3). Consequently, to relieve the issue of long lead-times in manufacturing development, it is essential to adopt a proactive approach and prepare the organization for the future in terms of promising manufacturing technologies.

Several of the respondents mentioned the overall product should be the input to the roadmapping process and initiate the changes needed in manufacturing. Respondent AA1 described how product development receives inputs directly from the market, while manufacturing development gets inputs from the product development department. However, respondent AA3 and AB1 argued that this way of working becomes problematic, thus manufacturing changes often require longer lead-times than product changes. This has resulted in that manufacturing development in some cases has been involved too late and instead of using new more efficient manufacturing technology solutions, traditional methods have been chosen due to time constraints (AA6, AB1, C1, AB3, & AA8). If manufacturing development gets involved in an earlier stage, the possibilities to test and validate the new manufacturing technologies increase. This will result in new ideas on how to manufacture the product more efficiently and simultaneously challenge product development on how to design a more manufacturable product (AA6, C1, AB3, & AA8).

Seven respondents active in manufacturing development highlighted the importance of having a long-term perspective to prepare the organization for the future. However, the manufacturing technology specialists AA8 and AA9, which both have to deal with every day manufacturing issues and long-term developments, emphasized the difficulty of prioritizing long-term activities with no immediate consequence. Most often, they have to focus on solving the manufacturing issues of the day, which implies less attention to long-term manufacturing development. On the other hand, the technology managers that are not involved in every day issues want the technology specialists to focus on long-term developments. The clash in specialists and managers time perspectives and focus areas is one factor in need of attention to become successful in technology roadmapping, thus the specialists request more time to dedicate to long-term manufacturing development.

Another issue brought up to discussion during the interviews was a fundamental difference between manufacturing development (department AA) and product development (department AB). Respondent AA8 argued the product development department only has to consider the development of new competitive products and not pay major attention to other factors in the organization. On the other hand, the manufacturing development department has to take the employees working in the organization into consideration, which implies that the theories of organizational change requires investigation. It is necessary to make everyone in the organization understand the purpose and benefits of a new process or activity in order to receive organizational support. It is vital to consider this aspect in technology roadmapping for manufacturing development, while it probably is not as important in technology roadmapping for product development.

6 Discussion

The discussion of the research project's results follows in subsequent sections. The topics for the discussion are similarities and differences between the literature review and the empirical findings, as well as differences between the respondents' opinions. The ambition is to discuss possible reasons for why these similarities and differences have emerged and provide additional material to nuance the answers to the research questions.

6.1 Technology Roadmap

The researchers identified a difference regarding the purpose with technology roadmap during the interviews. Management on higher hierarchical levels considers technology roadmap to be a visionary tool with the aim of opening the mindset of the employees, while individuals on lower levels perceive technology roadmap as a concrete tool or activity list to prioritize upcoming investments. In a similar sense, the empirical findings revealed that higher management tends to have a longer time perspective than lower levels, which have shorter time perspective due to their responsibility to keep production going. It is uncertain whether this is problematic or not, nevertheless it is crucial that both parties are aware of these differing aspects and communicate with each other regarding the purpose of technology roadmap.

The difficulty of disaggregating market demands to specific development activities in each function is a challenge according to the respondents. The researchers suspect this problem might have its origins in the traditional functional structure of the organization, thus such structures can hinder synchronization of activities across functional borders. For instance, respondent AA1 mentioned that different functions are on different levels in their roadmap efforts, which further indicates that the collaboration across borders can be difficult to achieve. Hence, it is essential to stimulate cross-functional collaboration to ease future state disaggregation and create consensus regarding each function's future developments.

6.2 Technology Roadmapping

One recurrent aspect regarding the definition of the current state in the organization was to use pilot sites, which follow current best practices in manufacturing. This is an efficient measure when it comes to mitigating risks, due to the manufacturing concepts' proven functionality. However, there is a risk that other sites fall behind when they try to adopt the processes used at the pilot sites, thus the best practice process is in constant change and long lead-times make it difficult to stay up to date. It might be that the manufacturing technologies already are obsolete and replaced by other technologies when the various sites implement them.

There is a mismatch between the literature and the respondents regarding the need to use multiple futures and scenarios for the roadmap. The researchers have one suggestion on how to deal with this issue. The suggestion is that the desired future state is one fixed picture of where the organization should be in the future. Moreover, it might be a good idea to develop a number of different scenarios on how the market and general business environment could develop in the years to come. The roadmaps should then illustrate how the organization should reach the future state in each one of these scenarios, thus it enables the organization to prepare itself for alternative futures.

The researchers have identified two possible reasons for why the opinions between respondents from department AA and AB differ regarding the use of parallel tracks in the roadmap. First, it might depend on the nature of their development activities, thus AA focuses on manufacturing development and AB on product development. Product development might include more uncertainties regarding technologies than manufacturing development due to market demands, which makes it essential for product development to use parallel tracks. For instance, the classic example of when Kodak failed to foresee the future market requirements illustrates the level of risks product development has to deal with. As the manufacturing technologies do not directly affect the end customer in that sense, it might be the case that manufacturing development does not need to use parallel tracks in the roadmap to the same degree as product development. Second, another reason for why department AA does not prefer to work with parallel tracks might be that it never have used parallel tracks in the past and is more comfortable of only working with one track at the time.

Regarding technology maturity assessment, TRL frequently occurred during the interviews while only three respondents mentioned MRL. The reason for why TRL was more common might be that it is the older of the two scales and has therefore had more time to gain momentum. MRL is more specific to manufacturing and has the TRL scale as original base, which is one possible explanation for why MRL is not as common as TRL. Regarding technology roadmapping for manufacturing, the MRL scale obviously has larger potential to bring success to the organization due to its feature to take a wider range of manufacturing aspects into consideration.

Another difference between the respondents was whether it is necessary to use indicators to measure the progress of the roadmap's activities or not. A reason for this issue might be that different individuals tend to have different perspectives on the purpose with technology roadmap. Some respondents consider the roadmap to be a visionary tool that illustrates a qualified guess regarding the organization's future while others expect it to be more concrete and a truth of what the organization has to fulfill in terms of technology development. It is once again vital for the organization to clearly communicate the purpose with the roadmap and how to use it. Neither one of the perspectives are necessarily wrong, however it is important to create consensus regarding the issue of measuring progress.

6.3 Important factors related to manufacturing

It was apparent during the interviews that product development often sets the boundaries for manufacturing development. Some respondents also mentioned that manufacturing development has to consider a wider array of inputs than product development (e.g. employee safety, work environment, & productivity). On the other hand, the researchers want to question this issue, thus product development depends on inputs that do not directly affect manufacturing development. For instance, product development has to take inputs from the market, customers, competitors, and government into strict consideration to become successful. One recurrent topic during the interviews was the improvement of parallel development of manufacturing and product, thus it enables both parties to influence the product design and satisfy all stakeholders and their requirements.

Another recurrent aspect during the interviews was that the primary task for manufacturing is to keep production going, while manufacturing development is a secondary task. The respondents considered product development to only have one primary task, which is to develop new products. The respondents mentioned this difference between product and manufacturing development several times and it obviously affects the conditions for how the different departments work with technology roadmaps. The fact that manufacturing has two tasks might lead to resource constraints, as both tasks might request and allocate the same resources or competences.

The empirical findings show that it is desirable to use "on-the-shelf" solutions, which means that the organization investigates new manufacturing technologies and put them on hold until the opportunity to implement them emerges. The researchers believe it is difficult to have "on-the-shelf" solutions when it comes to manufacturing due to the main priority of producing goods. Incremental and continuous improvements to existing machinery are more likely and realistic than to develop technology concepts with no immediate application. Nevertheless, if manufacturing development adopts a new way of thinking and starts to challenge product development regarding new manufacturing technologies, it might trigger the development of "on-the-shelf" solutions. A change in mindset regarding manufacturing’s' main priority has started to emerge within the case organization.

7 Conclusion

The conclusion of the research project follows in subsequent sections and has the purpose to answer the main research question "How can Technology Roadmapping be applied to Manufacturing Development?". The literature review, empirical findings, and analysis follows the structure of the research sub-questions and has therefore provided inputs and answers to these. The conclusion merges these answers to provide an answer for the main research question. The theoretical and practical implications and suggestions for future research end the conclusion.

The results of this research project indicate it is appropriate to apply the technology roadmapping process provided in the literature review to manufacturing development. The recommendation for department AA is to set up a roadmapping process in which individuals on lower hierarchical levels develop the roadmap content that a control entity then validates and reviews. It is further important to locate this control entity at a hierarchical level on which the managers still have detailed knowledge of manufacturing technologies, thus it increases the probability to make the right decisions. It is also necessary to assign one individual the role as process owner as a way to ensure constant monitoring of the roadmapping process. Another issue to deal with is the length of the interval in which the organization updates the roadmap. The result shows that this issue really is a question of balancing momentum and workload, as too long intervals cause the concept to lose momentum and too short intervals create an unsustainable workload for the employees. Hence, it is vital to find this balance and set up structures for how to update the roadmaps.

The roadmapping process in the literature review is generic in the sense that it is not customized to product development or manufacturing development. However, the process can easily be adapted to fit in both product and manufacturing development. The differences between these emerge in the details of the roadmapping process's phases and sub-stages. For instance, maturity assessment with Manufacturing Readiness Level (MRL) is highly applicable for manufacturing development, while Technology Readiness Level (TRL) is more suitable to use within product development. The research project also indicates that the need for parallel tracks in the roadmap differs between product and manufacturing development. Product development has to hedge itself for uncertainties in the market and use parallel tracks, while manufacturing development is not directly exposed to the market and can go about without using parallel tracks in the roadmap. Technology roadmapping for manufacturing also needs to take into consideration the employees in the organization and clearly motivate the purpose with the proposed changes, however product development does not need to consider this aspect to the same degree. Consequently, each organization has to investigate the fundamental building blocks in the roadmapping process and customize them to the organization's specific needs and development activities.

To further make the roadmapping process applicable for manufacturing development, it is a necessity to include factors especially important in manufacturing. For instance, the issue that manufacturing has as primary task to produce products and secondary task to develop new technologies needs careful consideration. It has to be clear which resources and competences that should dedicate their time to long-term manufacturing development and which that should focus on short-term issues related to the daily performance in production. If this is unclear, the risk is that the organization puts too much attention to short-term issues and neglects the important long-term manufacturing development. The empirical findings showed that it sometimes is difficult to generate high quality inputs to the roadmap and this becomes even more problematic for manufacturing development, which has a wide spectrum of stakeholders and requirements to consider. It is probably necessary to include both external and internal stakeholders in the roadmap development as a way to ensure that the roadmap has its foundation in correct and accurate information. As the quality of the roadmap is dependent upon its input information, it is essential to set up routines around the issue of generating high quality inputs.

7.1 Theoretical and Practical Implications

The main theoretical contribution in this research project is the investigation of manufacturing specific factors related to technology roadmapping. Literature on technology roadmap most often relates to technology development in general or product development in particular. The literature review includes one article on technology roadmapping in manufacturing, which opens up for the possibility to fill a gap in existing literature.

The main practical contribution is the customized technology roadmapping process for manufacturing. The process is generalizable and with minor company specific adjustments, it should be able for any manufacturing company to use. The technology roadmapping process describes how manufacturing companies can use roadmaps in their endeavors to develop the next generation manufacturing processes and identify vital aspects to strengthen their competitive advantages.

7.2 Future Research

The overall focus of this research project has been to develop a technology roadmapping process for manufacturing. During the project, the researchers have encountered several aspects that were out of the scope of this research project and thereby need further investigation. One interesting question that emerged relates to progress indicators and if and how companies should measure roadmap progress. As the respondents' answers were dissimilar, further research within this area may be appropriate. One conclusion is that the use of progress indicators in relation to technology roadmap seems to depend upon the purpose with the concept. It is necessary to research if it is a requirement to measure the progress and, if so, how to do it.

Another area that needs further research is the relationship between the TRL and MRL scale. An interesting question is how companies can develop new products and simultaneously consider the manufacturing technologies needed to produce the products. The balance between innovative solutions within manufacturing and innovative products will become increasingly important to stay competitive on a global market. It would be interesting to look into practical examples of companies that use both these scales and identify success factors to assess the maturity of product and manufacturing technology in parallel.

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9 Appendix A: Interview Guide – Managers Department AA

Name:
Company:
Position:
Department:

1) For how long have you been working at the company and in the current position?
2) What is your main area of responsibility?
3) How do you prepare manufacturing processes for the future currently?
    a. Specific work practices?
    b. What have worked well/bad?
    c. Why have you used these work practices?
    d. What are the most important factors to consider when you prepare manufacturing processes?
    e. How do you coordinate development activities across functional areas?
4) What does technology roadmap mean to you?
5) What is the purpose behind the usage of technology roadmap?
6) What opportunities and challenges do you perceive with technology roadmap?
7) What do you consider most important to make the concept work in a successful way?
8) How should a roadmap be developed?
    a. Which steps should be included?
9) Which individuals should be involved in the roadmap development?
10) How do you want the roadmap to be illustrated?
    a. Which levels are necessary?
11) What information should be provided in the roadmap?
12) How do you scan the external environment for new technologies?
13) How do you define the current state in terms of technologies?
14) How do you define the future state in terms of technologies?
15) How do you define the activities in the roadmap?
16) How do you identify technology alternatives?
    a. Do you use parallel tracks?
    b. How and when do you do decide upon which path to pursue?
17) How do you assess the maturity level of each technology?
    a. When should a technology be considered as mature enough?
    b. How to make sure the organization is mature for the technology?
    c. Do you use indicators for maturity level in a technology?
18) How do you consider risks and uncertainties in each activity?
19) How should coordination and aggregation of roadmaps be dealt with?
20) Who should be engaged in the team that revises technology roadmaps from lower levels in the organization?
21) How should managers use the roadmaps developed on lower levels in the organization?
22) How should these roadmaps be prioritized?

23) How do you ensure that the roadmaps are of high quality?
24) Can you identify any differences between product and manufacturing development?
25) What indicators do you use to make sure the roadmap is fulfilled?
26) How often do you revise the roadmap content?
27) What time horizon do you consider appropriate?

10 Appendix B: Interview Guide – Technology Specialists Department AA

Name:
Company:
Position:
Department:

1) For how long have you been working at the company and in the current position?
2) What is your main area of responsibility?
3) How do you prepare manufacturing processes for the future currently?
    a. Specific work practices?
    b. What have worked well/bad?
    c. Why have you used these work practices?
    d. What are the most important factors to consider when you prepare manufacturing processes?
    e. How do you coordinate development activities across functional areas today?
4) What does technology roadmap mean to you?
5) What is the purpose behind the usage of technology roadmap?
6) What opportunities and challenges do you perceive with technology roadmap?
7) What do you consider most important to make the concept work in a successful way?
8) What kind of support do you consider yourself to be in need of to develop a technology roadmap?
9) How would you proceed to develop a technology roadmap?
10) Which individuals and competences need to be a part of the team?
11) What do you consider the management's role to be in the work process with technology roadmap?
12) How do you scan the external environment for new technologies?
13) From where do you receive the inputs and guidelines to the roadmap?
14) How would you like to define the activities in the roadmap?
15) How do you identify technology alternatives?
    a. Do you see the need to use parallel tracks?
    b. How and when do you decide upon which path to pursue?
16) How do you assess the maturity level of each technology?
    a. When should a technology be considered as mature enough?
    b. How to make sure the organization is mature for the technology?
    c. Do you use indicators for maturity level in a technology?
17) How do you consider risks and uncertainties in each activity?
18) Can you identify any differences between product and manufacturing development?
19) How often do you consider the roadmap content should be revised?
20) What time horizon do you think is suitable when working with technology roadmaps?

11 Appendix C: Interview Guide – Benchmark study

Name:
Company:
Position:
Department:

1) For how long time have you been working at the company and in the current position?
2) What is your main area of responsibility?
3) What does technology roadmap mean to you?
4) For how long have you worked with technology roadmap?
5) What is the purpose behind the usage of technology roadmap?
6) What opportunities and challenges do you perceive with technology roadmap?
7) What do you consider most important to make the concept work in a successful way?
8) How do you use the concept?
9) How should a company prepare itself for the technology roadmap concept?
10) Do you use technology roadmap on different hierarchical levels?
11) How do you aggregate these to one comprehensive roadmap?
12) Is the roadmap tailored to your specific needs or is it based on a standard template?
13) How is technology roadmap communicated throughout the organization?
14) What information is provided in the roadmap?
15) Which individuals are involved in the roadmap development?
16) How do you scan the external environment for new technologies?
17) How do you define the current state in terms of technologies?
18) How do you define the future state in terms of technologies?
19) From where do you receive inputs and guidelines?
    a. How should these be prioritized in the roadmap?
20) How do you define the activities in the roadmap?
21) Is there a need to have different alternatives (scenarios) for the future?
22) How is the roadmap illustrated?
    a. Which levels are included?
23) How do you identify technology alternatives?
    a. Do you use parallel tracks?
    b. How and when do you decide upon which path to pursue?
24) How do you assess the maturity level of each technology?
    a. When should a technology be considered mature enough?
    b. How do you make sure the organization is mature for the technology?
    c. Do you use indicators for maturity level in a technology?
25) Which indicators could be relevant to measure each activity’s progress?
    a. How do you consider risks and uncertainties in each activity?
26) Who are involved in the validation of roadmaps?
27) How do managers use the roadmaps developed on lower level in the organization?
28) How should these roadmaps be prioritized?
29) How do you ensure that the roadmap is of high quality?

30) Can you identify any differences between product and manufacturing development?
31) How often do you revise the roadmap content?
32) What time horizon do you consider appropriate when working with technology roadmaps?