MASTER THESIS

TECHNOLOGY-ROADMAPPING IN A PROJECT-DRIVEN ORGANIZATION

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EXECUTIVE SUMMARY

The master thesis project has been carried out at Siemens Special Machines (SM), a leading company in the special drives industry. It develops, design, produces and manufactures highly customized, complex electrical machines for business customers. As a consequence, the business is project-driven, which means that it is always dependent on the immediate needs of current customers. This has many effects on the organizations and the management of technologies. Short-term focus in nearly all parts of the organization, allocation of resources to immediate issues, and the breadth and depth of technologies needed to produce such complex machines are only an extract.

To tackle these problems, Siemens SM decided to implement technology-roadmapping (TRM) into their organization. But what became obvious is that such a TRM process has to be developed for their specific situation, not only to make it fit to their individual goals, but also to make it fit to the specific demands of a project-driven organization.

This point marks the beginning of this master thesis. Embedded in the official project at Siemens Special Machines, the goal of the thesis had been to develop a TRM process for project-driven organizations, and to find out how it can be implemented in such an organization. Therewith not only supporting and facilitating the project progress at Siemens, it also complemented the literature about TRM.

Led by the research question (*"What is an appropriate TRM process for a project-driven organization, and how can it be implemented in the organization?"*), the methodology was split into several consecutive steps.

At first, an initial theory-based TRM approach, consisting of the roadmapping- and implementation process, has been developed based on the literature about TRM and project-driven organizations. Constituting merely a basis, the theory-based TRM approach has been iteratively evaluated and improved in two separate group meetings with the Siemens project team (i.e. experts, project leader, external consultant, CKI[1]) prior to the implementation. As a consequence, the resulted TRM approach had a strong theory base, went through two evaluation-synthesis cycles, and was accepted and understood by the project team.

[1] CKI (Center of Knowledge Interchange) is a cooperation between Siemens and top-class universities to enhance knowledge interchange through common (research) projects

After this initial design phase, the TRM approach has been implemented into Siemens SM by making a first run-through. While the implementation constituted a practical test, the methodology of this thesis focused on the identification of the TRM approach´s strengths and weaknesses throughout the entire implementation. Based on an evaluative description and further theoretical insights, final suggestions for improvement of the developed TRM approach were given.

Throughout the project, the TRM approach has been adapted several times, even during the implementation. As an answer to the research question and as a final result of this master thesis, an appropriate TRM approach should have the following distinctive characteristics when applied in a project-driven organization:

- People-centred (i.e. workshop-based): involve all relevant experts of the organization to tap into the tacit knowledge embodied in the experts; and seek external consultancy for mediation and methodology
- Each workshop needs a preparation phase (collect information input) and a post-meeting (verify results) to cope with the complexity of information
- Collect and link information/knowledge about market/business drivers (esp. regulations and political drivers), product features, technologies (i.e. product and production technologies) and resources for the future to feed the separate layers of the roadmap
    - Recommended are seven workshops to cope with the complexity of information
    - Define precise market segments in the market workshop to deal with and display the diverse demands
    - Input/ consider/ develop radical technological solutions (=bi-directional roadmapping) to compensate for the prevailing short-term view and the innovation imbalance
    - Enter external technological developments to be able to process developments (i.e. mostly radical innovations) where the competence lies outside the own organization
- Integrate the TRM process into central- and project-related processes to repeat the process regularly and support the management of technologies

Although already satisfied with the results of the first run-through, Siemens was given recommendations for their further implementation based on these findings.

The first recommendation is to finish the integration of the TRM process, which comprises the integration of the roadmap results and the roadmapping process into the organizational systems and processes.

Thereafter, processes should be created/ implemented to close the gaps which were identified in the implementation and evaluation, so that finally all undone activities (i.e. identification of radical innovations, entering external developments, allocation of resources to the technologies) can be executed in the next run-through of the roadmapping process.

Executing what is recommended means that the process at Siemens conforms what is formulated in the findings of the thesis and compensates for the existing weaknesses. As a matter effect, the process becomes better and more valuable in the next years by being implemented adequately in the organization and by bringing valuable strategic relevant information for their business planning.

LIST OF FIGURES AND TABLES

ABBREVIATIONS

B2B	Business-to-Business
cf.	confer, "compare"
CKI	(Siemens) Center of Knowledge Interchange
CoPS	Complex Products and Systems
e.g.	Exempli gratia = for example
esp.	Especially
etc.	Et cetera
i.e.	Id est = that is
OEM	Original Equipment Manufacturer
R&D	Research and Development
TRM	Technology-roadmapping
SM	Special Machines (Organizational unit within the Siemens Corporation)

Contents

1 INTRODUCTION

Technologies do have a fundamental relevance for today´s economies and organizations (Zahn, 2004). According to Grossman & Helpman (1994), innovative technologies are one of the major antecedents for economic growth. On a micro-economic level, organizations find themselves in a race to innovate technologically in competition to each other in order to reap the advantages and the respective privileges related to a dominant technological position (Zahn, 2004).

What becomes an obvious necessity for the individual organization as a player in that race is to invest resources into technologies. To let this investment be as effective and efficient as possible, organizations deploy processes, commonly and comprehensively described as technology management (Spath, Pastewski, & Lang-Koetz, 2010). More precisely, technology management comprises the identification, selection, acquisition, development, exploitation and protection of technologies (Gregory, 1995). Among the many tools available, *"technology-roadmapping represents a powerful approach for supporting technology management and planning of the firm"* (Phaal, Farrukh, & Probert, 2001, p. 367). By bringing together the different business processes, considering relevant internal and external factors and considering the time dimension, it combines the technology- and market perspectives over time (Phaal & Farrukh, 2001) .

Nowadays, many companies are applying technology-roadmapping, and it has been widely adopted in different industries and organizations (Phaal et al., 2001). Likewise, the project principal for this master thesis, Siemens Special Machines (SM), has decided that technology-roadmapping can be of a high value for them. Acting in a market and industry where product and process technologies are of a vital importance to be competitively superior, the quest for technological innovation is high for Siemens SM. Because they are already technology leader in most of their customer markets, the issue of strategic technology management becomes even more important since the stakes are high in the light of the position to hold and defend. Awareness about weaknesses in long-term technology management led to the decision to customize a TRM process and to implement it into the organization in order to enhance their technology management and technological R&D.

Although it is well known that such a TRM process has to be specifically customized to the subject organization (e.g. Groenveld, 1997; Garcia & Bray, 1997; Phaal et al., 2001; Lee & Park, 2005; Gerdsri, Assakul, & Vatananan, 2010), there is one significant aspect about Siemens SM that demands special attention when designing and implementing a TRM process. This difference is that they produce complex, customer-tailored products, leading to a project-driven approach to business.

This is exactly where the focus of this thesis lies on - a TRM process and its implementation in the context of a project-driven organization. What the specific situation of Siemens SM is, what exactly technology-roadmapping and a project-driven business means, and why this topic is of relevance for a master thesis are explained in the following.

1.1 Company Profile and Situation of Siemens Special Machines

Siemens SM is a manufacturer of large electric drives and generators. It develops, designs, produces, and manufactures customized special machines for end customers and OEMs in B2B markets.

Since its foundation in the beginning of the 20th century, many innovations have left their plant which have affected the technological state-of-the-art and forced competitors to follow. Being industry technology leader, and having the benefits of the corporate parent, Siemens, Special Machines has gained a rather strong market position over the last decades.

Despite the dominance, a lack of a sufficient long-term perspective with respect to technology research and development concerns the R&D department. In addition, the separate departments, i.e. sales, marketing, engineering, and production, do not have aligned roadmaps, and communication and future planning of the respective departments is reduced to short-term, order-specific issues.

As a consequence, the head of the R&D department has initiated a project to tackle these problems and to develop a technology roadmap. The project started in cooperation with the CKI (Siemens Center of Knowledge Interchange). The method chosen to support this process is – as introduced above – technology-roadmapping. The main goals of the project are to develop a TRM process suited for Siemens SM´s situation, to prototype it once by making a complete run-through, to derive a first technology roadmap, and to integrate the process in order to make this process a continuous organizational process.

As part of the project team and an employee at Siemens, my task is to support and document the development of an appropriate TRM process, to accompany and support the implementation, and to document the entire procedure.

Siemens´ expectations with respect to this master thesis, and therefore my tasks for this study, are to facilitate the development and to validate the appropriateness of the TRM process and its implementation, and to give a recommendation for their further implementation. In how far this master thesis can satisfy these expectations is explained in the following sections.

1.2 Practical Problem and Theoretical Gap

That Siemens SM wants to have a TRM developed is in itself not a challenging problem. The TRM literature offers several viable approaches for TRM processes and their customization (e.g. EIRMA, 1998; Phaal, Farrukh, & Probert, 2004; Lee & Park, 2005b). However, the situation of a project-driven business was never an issue in the literature, though demands attention.

Taken the example of Siemens SM, as a manufacturer of special electric machines, they serve diverse B2B target markets. Their products need to be highly customized to meet the performance requirements of their diverse customer base. Practically every machine is different, with the customization already starting in the engineering department.

Hobday (1998) defines such high cost, customized, engineering-intensive B2B products "complex products and systems (CoPS)". He states that CoPS-producing organizations require more breadth in technologies than other organizations, and that there is a difference in the dynamics of innovation in contrast to more mass-produced goods. He further says that CoPS are produced in projects due to the tailor-made subsystems and the individual composition of the overall product.

Also in the case of Siemens SM, every customer order represents a unique project, ranging from the development to the delivery of the complex machine. This complexity and individuality in their products demands to be project-driven in order to be able to react accordingly to their customers´ requirements. This leads us to the following explanation of what a project-driven organization is considered as in this thesis:

"A project-driven organization produces tailor-made, complex B2B products in project-form, with the attention (e.g. resource allocation) on the customers´ specific and immediate needs."[2]

Although the literature review (in sections 2.2 and 2.3) gives a more elaborated picture about the distinctive situation and requirements of a project-driven organization, it already becomes

[2] Own working definition for the purpose of this master thesis

obvious at this point that the prevailing conditions very much differs from organizations with batch/series production.

Having agreed that the consequences of being project-driven are extensive on the organization, the question arises if existing TRM literature considers this aspect and thus offering a solution for Siemens SM´s situation.

About technology-roadmapping much has been written since Motorola developed the approach in the 70s in order to support their long-range strategic planning (Willyard & McClees, 1987). In the following years, this approach has been adopted by a number of organizations and has been adapted according to their specific needs (Lee & Park, 2005).

Beginning in 1997, two researchers from Cambridge University, Phaal and Farrukh, have started to study this method and pioneered in the theoretical development of TRM, which has led very much to the generalization of the method. Since then, many papers have been published about TRM, and many case studies demonstrate where and how TRM has been applied to a specific organization in a specific context.

Because of the generic nature of the developed TRM processes, the literature suggests methods to customize the architecture and the processes to the specific needs of the organization (EIRMA, 1998; Phaal, Farrukh, Mills, & Probert, 2003, Phaal et al., 2004; Fleuryl et al., 2006). However, according to Lee and Park (2005), TRM is a useful and flexible approach; but there is still a problem concerning how to make the approach fit to specific needs, and to accommodate unusual circumstances. They state that it leads to problems in organizations if there is a misfit, since it is very important to flexibly alter the generic roadmapping process to address firm-specific circumstances and environmental conditions. That is why there are numerous published papers about TRM processes applied to specific circumstances, be it on industry or organizational level, in order to meet the specific, most contextual requirements.

Despite the manifold publications, the contextual requirement of being project-driven is disregarded until now. TRM literature, including the approaches of customizing the TRM process, only generally addresses the elements of roadmaps and roadmapping that are subject to change. Guidance about *how* to actually design the process is – apart from the general proposition *that* is should be adapted – not given for specific circumstances, including the project-driven character.

This leads to the conclusion that although the TRM literature is extensive, there is still a gap in the literature about how an appropriate TRM process and its implementation might look like for the situation of a project-driven organization.

1.3 RESEARCH GOAL

The main goal for Siemens Special Machines is to have a suitable and functioning TRM process implemented into their organization. "Suitable" means that it fits to their specific situation, particularly fitting to their project-driven business. "Functioning" means that the process produces reliable roadmaps. Since the TRM literature possesses a gap with respect to the project-driven character of an organization, the research goal for this master thesis is:

"Develop an appropriate technology-roadmapping process, which can be implemented in a project-driven organization, in order to support Siemens Special Machines in their TRM development and implementation project."

1.4 CENTRAL RESEARCH QUESTION AND SUB-QUESTIONS

To conform to the requirements of the research goal, the research focuses on the identification of an appropriate technology-roadmapping process and implementation in the context of a project-driven organization. Therefore, the guiding central research question is:

"What is an appropriate technology-roadmapping process for a project-driven organization, and how can it be implemented in the organization?"

"Appropriate" relates to the quality of the TRM process. This means, that it should consider the requirements coming from project-driven business; and that it should produce reliable roadmaps that can be used for strategic technology decision-making.

The central question consists of two parts, with each forming a separate sub-question:

1. ***What is an appropriate technology-roadmapping process for a project-driven organization?***
   → In the first step it is important to find out what an appropriate TRM process constitutes. Therefore, in a literature review, requirements are to be identified, particularly those coming from a project-driven business.

2. ***How can this technology-roadmapping process be implemented in a project-driven organization?***
   → Once the TRM process is developed, it is essential to embed it into the process of implementation. In the first step, again, literature is used to plan the implementation.

After having initially developed a theory-based approach consisting of the TRM process and its implementation, the approach is evaluated and improved by experts, and finally implemented into Siemens SM. Analysis of the implementation allows verifying the effectiveness of the TRM approach on the one hand. On the other hand, the approach can be improved based on the feedback gathered during implementation, and allows giving Siemens SM a recommendation for their further implementation. By following this procedure, the two sub-questions can be answered by having both, a theoretical and an empirical basis.

The logical setup and methodology are discussed more elaborately later in thesis in the respective parts (see sections 3.1 and 4.1). But before continuing, it is important to set the context and define the theoretical frame.

1.5 Theoretical Frame

From the research questions, the theoretical frame can be easily derived. Mainly two fields are needed and define the theoretical boundaries. The first one is technology-roadmapping literature, which includes the process of roadmapping, the outcome of a technology roadmap, the customization of both (process and roadmap) and the implementation of roadmapping. The second theoretical field is that of project-driven organizations. Well aware that this is a construct specifically defined for this thesis, it encompasses the literature about "Complex Product and System" (CoPS), as previously already indicated.

In the following, a brief view in each field is presented, which leads to a better contextual understanding. Furthermore, it is clarified what the scope of each is and how the terms are defined for this thesis.

Technology-Roadmapping (TRM)

TRM process - A process is defined as *"a series of things that are done in order to achieve a particular result"*(Hornby, 2005). Related to the business context, a process can be defined as *"a sequence of interdependent and linked procedures which, at every stage, consume one or more* *resources to convert inputs (data, material, parts ,etc.) into outputs; these outputs then serve as input for the next stage until a known goal or end result is reached".* (BusinessDictionary.com)[3]

A technology roadmap, accordingly, is then considered as the output of the TRM process. The interdependent and linked procedures which convert inputs and finally result in the technology roadmap are what is defined as the TRM process.

Over the years, many authors have constructed their own definition of what constitutes a TRM process. According to EIRMA (1998), the TRM process is an overarching process that integrates input from the relevant business processes. Groenveld (1997) states that technology *"roadmapping is a process that contributes to the integration of business and technology and to the definition of technology strategy by displaying the interaction between products and technologies over time, taking into account both short- and long-term product and technology aspects."* Phaal et al. (2003) further highlight the integration of market opportunities to display the development in technology that is linked to product evolution and market opportunities.

There are more definitions about roadmapping, which all have one core aspect in common. That is, that short- and long-term information from the existing business processes (i.e. market, product, technology) is brought together, linked, and displayed in a certain manner. It is not within the scope of roadmapping to produce new information, like for instance market projections and perspectives for the coming 10 years. Such processes should be ingrained in already existent business processes. In this example, market projections should be produced in the marketing department. The value of roadmapping rather lies in the alignment of the different perspectives of the organization and to search for connections between those. Visually enhanced in a roadmap format, this roadmap enhances decision making.

Consequently, an appropriate working definition for this master thesis is:

"A TRM process is an overarching process, consisting of interdependent and interlinked steps and activities that are necessary to bring together the critical business processes to align data, information, and knowledge from the market, products, and technologies, considering the short- and long-term perspective in order to create a technology roadmap."

[3] BusinessDictionary.com. Definition of "process." Retrieved March 15, 2012, from http://www.businessdictionary.com/definition/process.html

TRM process implementation - Implementation means “to carry something out”, or to “execute” something that has been previously planned (Hornby, 2005). In other words, implementation is itself a process; and this process builds on preliminary thinking.

With respect to TRM, it means that implementation is the process which describes the initial execution of the separate steps and activities of the TRM process in the organization. That implies two critical aspects to consider. First, the TRM process was previously not existent in the organization – at least not in that form – and is introduced for the first time. So, TRM is new to the organization and means that the organization is confronted with a change. Second, the TRM process and the implementation are inevitably interlinked and therefore dependent on each other. Thus, the TRM process and the respective implementation are to be considered together in one approach in order to design a TRM process that enables an effective implementation.

In this thesis, the implementation encompasses the first execution of the TRM process in an organization, from the first step of planning, over the first run-through of the process, till the final integration in the organization´s systems and processes.

Project-driven organization

Like already defined above (section 1.2), a project-driven organization produces tailor-made, complex B2B products in project-form, with the attention on the customers´ specific and immediate needs. With respect to the scope of the term, is essential to highlight that project-driven is not directly and exclusively associated with the organizational structure, as it is sometimes interchangeably used with the term project-based organization. A project-driven organization as defined here may indeed have a dominant functional structure, or it may have a pure project-based structure. But in all cases, the project-driven organization sees the customer-order as a project due to the aforementioned characteristics that contrast in many ways a mass-producing organization. Critical in that definition are the requirements coming from the diverse markets needs, the resulting complexity in products and technologies, and the dependency on immediate customer orders.

1.6 Theoretical and Practical Relevance

Having defined what the thesis is about both theoretically and practically, and having defined the theoretical boundaries, the question is now what the initial relevance is (see section 7.2 for the exact contribution to theory and practice based on the findings).

Reaching the study objective contributes in many ways to theory and practice. For theory, it complements to existing TRM literature, explaining what constitutes a viable TRM process for project-driven organizations, and how it is best implemented. Further, the construct of a project-driven organization is defined and clarified, not to mention the linkage that is created and analyzed between a project-driven organization and technology-roadmapping. Therefore, it also contributes to the literature of “complex products and systems” and that of a project-driven organization by offering a list of requirements that are necessary to consider for processes like roadmapping.

The practical contribution is more obvious, and is most direct and valid for Siemens Special Machines. As the developed process is implemented into their organization, they finally receive a theoretically and practically robust TRM process. Moreover, a recommendation for their further implementation increases the likelihood for a successful outcome of their project.

In a wider sense, however, it can be helpful for other project-driven organizations willing to implement such a process. The developed TRM process is more suitable for that context than the other, more generic TRM approaches. It is a helpful process to align interest of the different departments and to increase cross-functional communication, i.e. marketing, product management and engineering, with respect to future planning. This is critical within an organization that needs, on the one side, a strong focus on B2B customers to capture all their needs, and on the other side a strong resource/technology perspective to plan innovations in the long-term independent from immediate, short-term customer demands.

1.7 METHODOLOGY - OVERVIEW

The methodology that is necessary to answer the research questions basically consist of two parts. The first part deals with the development of an appropriate TRM process and its implementation. The second part is about the implementation and its evaluation into Siemens SM in order to test the TRM approach.

The thesis´ methodology therefore not only accords the project planning from Siemens, which is a major restriction, but also how van Aken et al (2006) suggest solving business problems (see section 3.1 for the precise description and justification of the methodology). In their methodology, they suggest to develop a solution design in an iterative way. Based on a theoretical developed design, the researcher should go through synthesis-evaluation loops to finally receive an implementable design. In the next step, van Aken et al suggest the implementation of the design, following an implementation plan. Finally, the implemented design is evaluated.

In accordance with van Aken et al, the methodology in the first part should lead to a theory-based and practically feasible TRM process which can be implemented into a project-driven organization (see figure 1). Therefore, an initial theory-based TRM approach is suggested that fulfils the conditions found in the literature about project-driven organizations (figure 1: (a) and (b)). Then, this initial TRM approach is presented to a group of experts and is critically discussed through which an iterative evaluation and adjustment is guaranteed (figure 2: (b) and (c)).

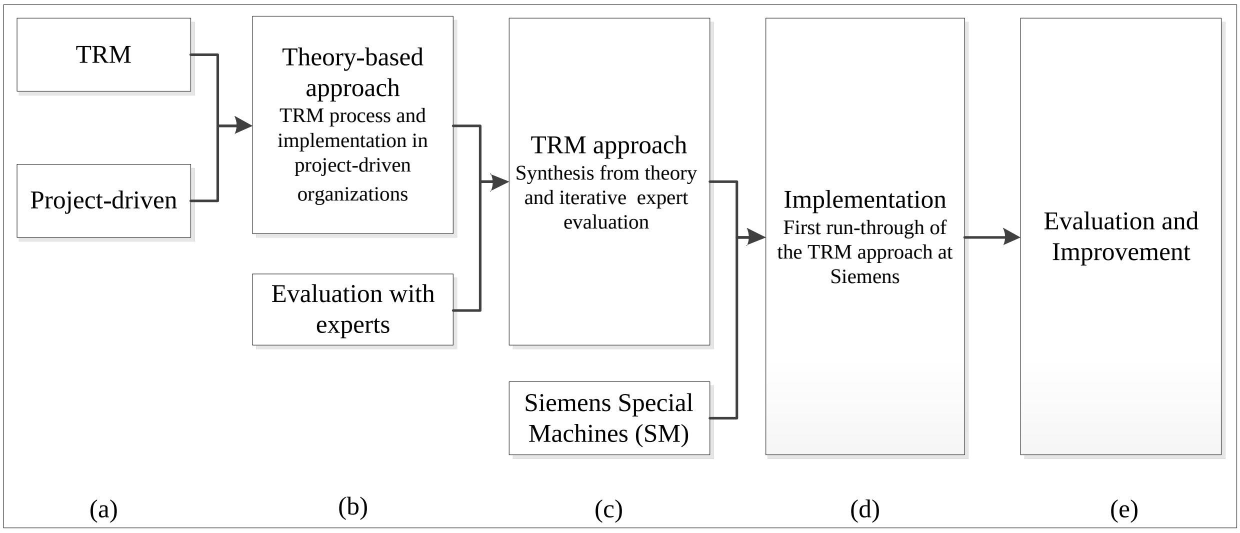

Figure 1: Macro-structure of the methodological approach

In the second part, the implementation and its evaluation should shed light into the practical application of the TRM approach, that is to find out what the strengths and weaknesses are (figure 1, (d) and (e)). From a methodological point of view, in this stage, it is important to collect appropriate data which can be analyzed in search for the strengths and weaknesses of the approach.

1.8 Structure of the Thesis

The set-up of the master thesis is aligned with the requirements and set-up of the Siemens project. This has many advantages, such as that the experts in the organization can be involved in designing the process, or that the implementation of the process may yield valuable feedback for the further improvement of the process. Thus, based on the research questions and the set-up of the project, the master thesis is structured as follows (see figure 2).

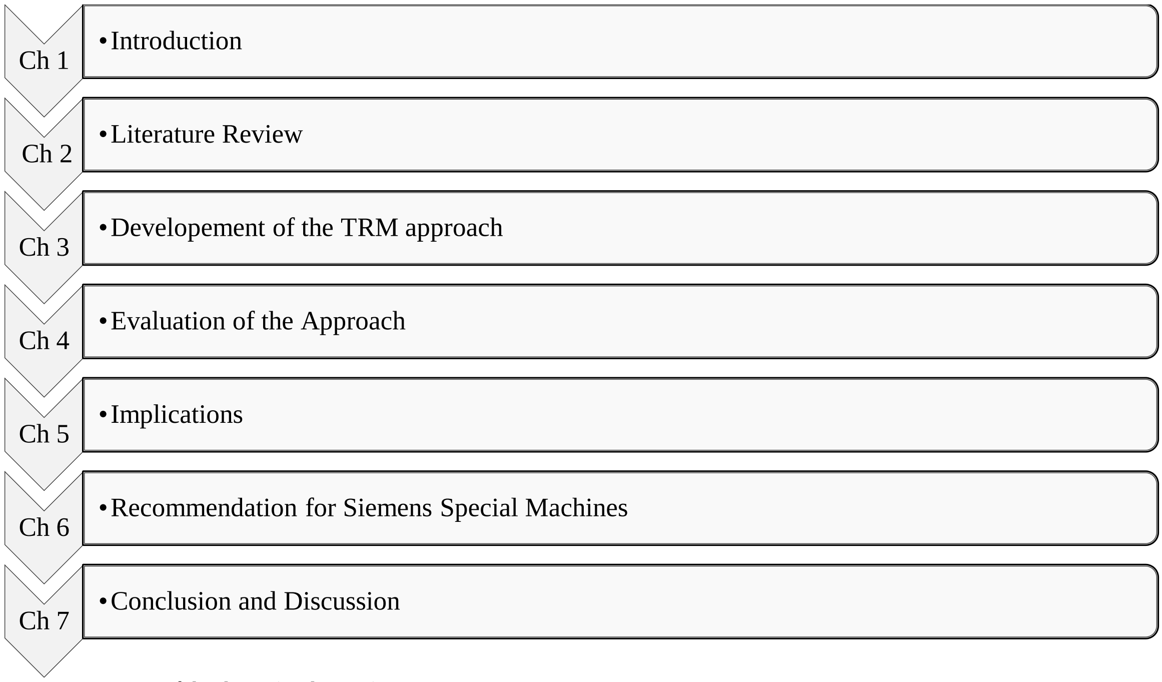

Figure 2: Structure of the thesis (in chapters)

Chapter two is devoted to an extensive and critical review of literature. Different approaches to TRM processes and its implementation are reviewed, as well as the literature that is relevant for the aspect of being project-driven. This chapter lays down the foundation for a theory-based TRM approach.

In chapter three, the TRM approach is developed. This includes the methodology about how the TRM approach, consisting of the TRM process and its implementation, is developed and the final TRM approach before to the implementation.

The fourth chapter describes the implementation. Emphasis is set on the aspects that went well and on those that were not that well. Based on this evaluation, the process can be further improved.

Based on these empirical findings and further theoretical insights, improvements for the TRM approach are suggested in chapter five.

This, in turn, serves as the basis for chapter six, where a recommendation for Siemens is formulated about how to proceed with the implementation.

Chapter seven concludes and discusses the thesis, especially in the light of the methodology. Additionally, further research in the field is suggested.

2 Literature Review

The theoretical foundation for this thesis is built up of two main fields, namely technology-roadmapping and project-driven organization. In the first two sub-chapters, these two fields are presented and reviewed respectively. Furthermore, an essential aspect of the thesis is to theoretically derive influencing factors of project-driven organizations for the TRM process and the respective implementation. Hence, in the final sub-chapter, these factors are identified by merging the two theoretical fields.

2.1 Technology-Roadmapping (TRM)

The literature about technology-roadmapping can be divided into three major parts. These parts are roadmaps as the output, roadmapping as the process leading to that output, and the implementation of the process leading to the first execution and the integration into the organization. Therefore, in the first section, general aspects about roadmaps and roadmapping are presented, including roadmap taxonomies, and intentions and purposes of TRM. Next, process and process customization literature are reviewed. And in the last section, the implementation literature for TRM is presented and compared.

2.1.1 Introduction to Roadmaps and Roadmapping

Roadmaps as used in the business literature are connected to the metaphor of the roadmap used for navigation purposes. From a bird´s eye view, the roadmap pictures a certain area and shows alternative ways to alternative goals. By selecting a specific destination, the traveller can chose among the alternative ways in order to reach that destination. Similar, several business-related aspects can be selected to put on the roadmap. By connecting the separate aspects in a logical way, several routes can be indentified among which the organizations can choose between partly rival alternatives.

A roadmap is generally visualized two-dimensionally and multi-layered (see figure 3). On the vertical axis, the business areas and their planning activities and milestones are placed. The horizontal axis is the time dimension along which the activities and milestones are allocated. As shown in the next section, both axes can be customized based on the purpose and context of the organization in subject.

The roadmapping approach is a creative method to analyze and simplistically visualize development paths of markets, products, services and technologies (Specht & Behrens, 2005).

By linking the market and the resource perspective, the organization is able to identify interdependencies and alternative routes (Phaal & Farrukh, 2001).

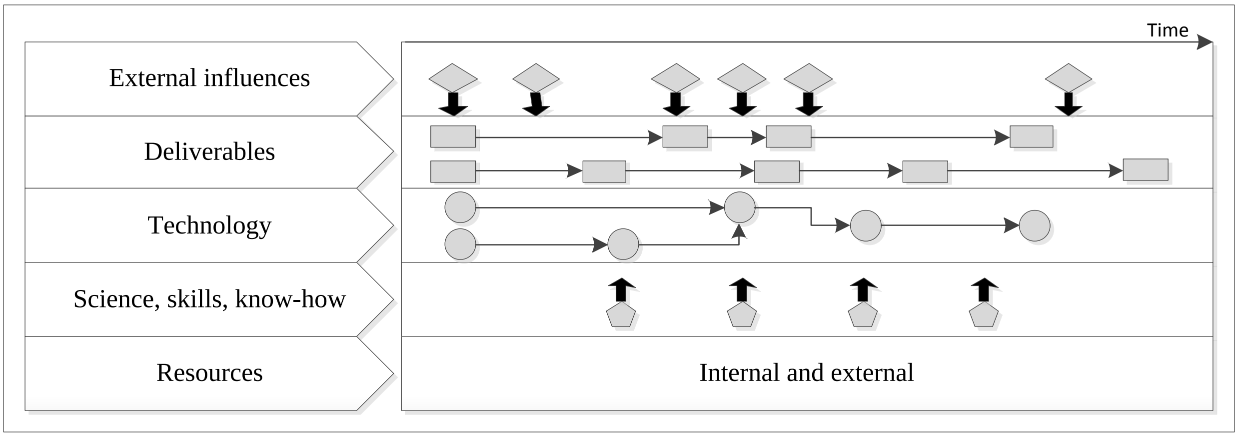

Figure 3: Generic roadmap, adopted from EIRMA[4]

Taxonomies of roadmaps

The term roadmap and technology roadmap has been used for different kinds of documents, and the TRM process can be deployed for several purposes. Kappel (2001, p.40) suggests a taxonomy based on two dimensions. One dimension is the level of orientation, namely if the roadmap is developed for the industry (macro level) or if it is developed for an organization (micro level). The other dimension divides the emphasis into the identification of specific trends and the positioning within a certain area. As a result, he defines the following four roadmaps:

- Science/ technology roadmaps: Setting of industrial goals based on industry trends
- Industry roadmaps: Setting of industry expectations based on position
- Product roadmaps: Scheduling of product introductions
- Product-technology roadmap: Aligning of internal decisions based on trends

Independent of the taxonomy, all roadmap formats include the time dimension as common characteristic.

Intention of using TRM

Technology-roadmapping follows a bunch of intentions and has many benefits, which are summarized by Bucher (2003). The first is directly bound to what is actually done in the process of roadmapping, which is to integrate business processes and to establish links between the perspectives. Further, because the perspectives are aligned, cross-functional communication and

[4] Source: adopted from EIRMA, 1998

interaction is needed and enhanced. TRM, with its focus on technology planning, improves the quality of technological decision making, and ultimately helps to coordinate and align technology-related projects and processes.

Purpose of TRM

For what TRM is actually needed, is best captured by Phaal et al (2001), who classified roadmaps by its purpose into eight groups. These groups are product planning, capability planning, strategic planning, long-range planning, knowledge asset planning, programme planning, process planning and integration planning. For each roadmap, apart from the roadmap design, also the process is different, since the process depends on the roadmap (cf. section 2.1.3).

2.1.2 Technology-Roadmapping – The Process

Technology-roadmapping is the process that is followed to develop and maintain the technology roadmap. Many authors have developed their own approach. In total, more than twenty approaches could be identified. Most of them differ in the kind of roadmap being produced, and therefore purpose being served.

For instance, the TRM process from Sandia National Laboratories leads to a product-technology roadmap and has its focus on the identification of requirements and drivers in order to select technology alternatives (Garcia & Bray, 1997). Abele et al.´s (2002) process produces a product-technology roadmap with the help of technology foresight and scenario planning and with the main focus on the communication between the engineering and production. Following Zurcher & Kosthoff´s (1997) process helps to identify types of projects and requirements. Kosthoff together with Schaller (2001) then suggest two diverging approaches, namely a workshop-oriented expert-based approach and, in contrast, a computer-based approach. Wildemann´s approach (2003) enables the adjustment of market and technology planning, the identification of synergies and allocation of resources. Gerdsri (2007) offers a dynamic approach by developing an operationalyzed process that is easily updateable as the market changes and the technology continues to develop.

Not every one of them serves as an optimal basis for this thesis. The first criterion and therewith the first requirement for the TRM process is that it has to fulfil a certain purpose. The purpose of this study depends on the previously described problem context of the project principal, Siemens. The purpose to be fulfilled is to enable strategic planning of technologies in the long term, linking the technology and market side of the firm in the form of a product-technology roadmap.

According to Phaal et al. (2004), the TRM process needs to be considered in parallel with the roadmap structure. That is why it is essential to make the conscious decision to focus on a certain type of roadmap fulfilling a certain purpose, which is in this case the product-technology roadmap linking the external market side with the internal resource side.

One of the approaches fulfilling this purpose is from EIRMA (1998), which is a group of organizations which has standardized roadmapping and developed a generic approach. Their approach aims to integrate the different business processes and their already existing information about markets, products and technologies. This allows exploring and mapping the evolution of market, products and technologies along the time dimension and to identify the linkages between the respective business processes.

Many authors, also some of the above-mentioned, based their approach on that generic proposition from EIRMA. One of the most comprehensive, most cited and internationally most recognized ones is from Phaal and his colleagues from the University of Cambridge. Phaal et al have published numerous articles about their technology-roadmapping approach ("T-Plan"), offering solutions to customize the approach and having a strong focus on the implementation of TRM.

For the theoretical basis of this thesis, the T-Plan offers an optimal foundation to develop the TRM process for project-driven organizations. The authors, as well as other authors, applied the T-Plan to many contexts. This demonstrates a certain robustness of the process on the one side, and flexibility on the other side. The level of detail is very high, since, in contrast to many other authors, Phaal describes not only the macro process of the main phases, but also elaborates on the micro processes. Offering comprehensive complementary literature about the implementation and customization, their stream ideally fits to the intention of this thesis.

T-Plan (University of Cambridge)[5]

The aim of this approach is to establish key linkages between the resources-side (technology resources) and the market-side (business drivers), and to identify important gaps in the market, product, technology intelligence.

The macro structure of the T-Plan consists of the three phases "planning", "roadmapping workshops" and "roll-out". These phases constitute the implementation phases of the TRM

[5] Main source (if not mentioned differently) is: Phaal, Farrukh, Mitchell, & Probert, 2003

process, which itself is embedded in the second phase, the roadmapping workshops (see figure 4). The second phase of the T-Plan is elaborated in the following, whereas the first and the third phase are handled in another section (cf. section 2.1.4), which deals with the implementation in detail.

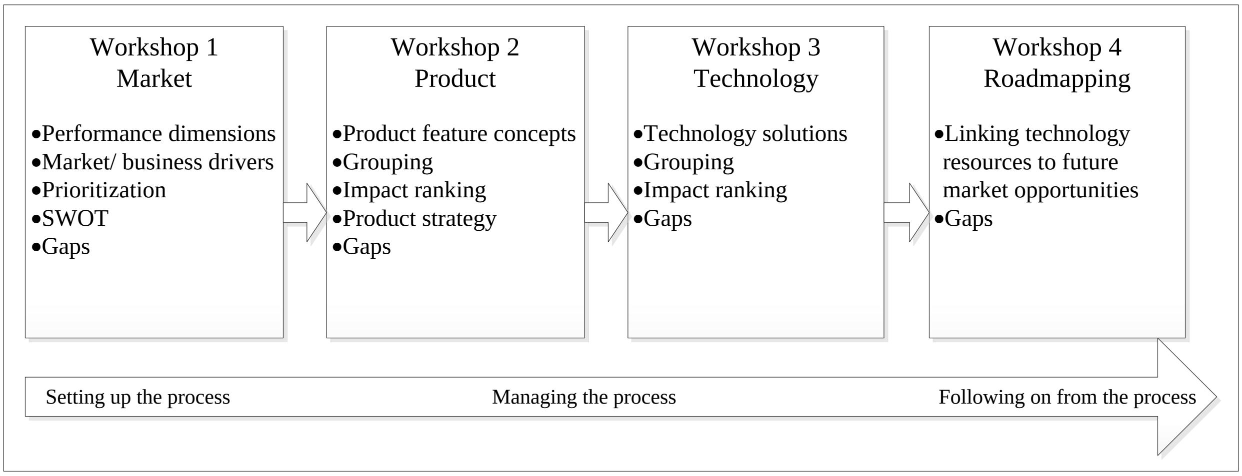

Figure 4: TRM process, extracted and adopted from the T-Plan[6]

For the TRM process in phase II, Phaal et al (2001; 2003) suggest a workshop-based approach, where each layer of the roadmap is handled in one workshop and analysis grids are used to identify and assess the relationships between the layers and sub-layers of the roadmap.

The main aim of the first workshop is to identify and prioritize market and business drivers, which can be derived from the most important performance dimension driving product development. In the second workshop, appropriate product feature concepts are to be identified that could satisfy the business and market drivers. After grouping the features, the relationships and impacts between the drivers and the product features are determined using a grid. In the third workshop, technological solutions to realize the product features are sought. After grouping them into technical areas, their impacts on the product features are discussed. The results of the three workshops are three business areas connected to each other through the respective grids. In the fourth workshop, the actual roadmap is charted using the output of the previous workshops. Key milestones are determined for each sub-layer (y-axis) along the time-axis (x-axis). Resources (e.g. technological programs; suppliers; skills, etc.) are identified and paths are drawn using the results from the impact ranking (i.e. grids) and by negotiation of the attending experts.

The main benefit of the workshop-form is that it brings together key stakeholders and experts. They then capture, share and structure knowledge about the issue being addressed, indentify

[6] Source: Phaal, Farrukh, Mitchell, et al., 2003

strategic issues and plan the way forward. Thus, the TRM process is structured by workshops, and the agenda of the workshops constitute the activities to follow (see figure 4).

In parallel to the workshop procedure, certain management activities are important; this includes facilitation of workshops, process co-ordination, and follow-up actions.

Phaal et al state that many of the benefits are derived from the roadmapping process rather than the roadmap itself. People are brought together from different parts of the business, which provides an opportunity for sharing information and perspectives. Highlighted is also the TRM process as a mean for supporting communication across functional boundaries in the organisation.

Assessment of the TRM processes

The T-Plan constitutes the best theoretical basis for the goal of this thesis and Siemens. It has a high level of detail and seems to be simple. The former aspect is related to a high practicability. The latter one is essential in the context of implementation. As explained in the next section, the adaption of the process to the organization is vital for the success. So, generic in nature, the standard process from T-Plan represents not more than the raw basis for the customization to make it fit to a project-driven organization.

2.1.3 Customization of Technology-Roadmapping

There is agreement among the researchers, that it is essential to adapt the generic roadmapping approach to the specific needs of the organization, since the potential benefit of deploying TRM may not be exploited otherwise (e.g. Groenveld, 1997; Garcia & Bray, 1997; Phaal et al., 2001; Lee & Park, 2005; Gerdsri, Assakul, & Vatananan, 2010). The adaption is based on the firm-specific situation and context and addresses the objective, timeframe, the TRM process and the roadmap architecture (Phaal, Farrukh, Mills, et al., 2003). In the international literature, there are two main groups dealing with the customization of technology-roadmapping, which are Phaal et al and Lee & Park.

Lee and Park (2005b) approach the customization from a perspective of modularization. The three phases of classification, standardization, and modularization finally allows customizing the TRM process driven by the purpose of roadmapping, the information source and the time frame.
Although this approach seems methodologically feasible, it is restricted to the variables entered into the three phases, and is therefore not helpful in the development of an appropriate TRM

process for this thesis. The customization from Phaal et al, instead, is not only more flexible but also an integrated part of the already above-explained T-Plan (cf. section 2.1.2).

Customization of the T-Plan (University of Cambridge)[7]

As part of the T-Plan, Phaal et al (2004) propose a standard process for developing a product-technology roadmap (cf. section 2.1.2). Alternatively, they offer a customization of this standard process in case the roadmap purpose differs.

Customization takes place in the planning phase of the T-Plan´s macro process. The two interdependent design elements to be customized are the roadmap architecture and the roadmapping process. Before considering the design, the context (scope of interest; focus for TRM; aims of TRM; available resources for the process) has to be discussed and defined in order identify the aims and boundaries that will affect TRM.

Having clarified this, the architecture and the macro- and micro process are designed. The architecture entails the timeframe and the layer and sub-layers (see figure 3 in section 2.1.1). The temporal dimension is dependent on how far the organization wants to "look" into the future with respect to the aspects to be mapped. The layers are determined based on the issues to be mapped, but basically there are three layers. The upper layer represents the drivers, or purpose, of the roadmapping activity (e.g. market/business drivers). The middle layer relates to the tangible system that satisfies the market and business drivers (e.g. products/ product feature concepts). The lower layer is the resource side (i.e. knowledge like technologies), that is needed to respond to the market and business drivers.

After the architecture is determined, first, the macro process has to be developed, which concerns the wider goal that is desired to reach. After that, based on the layers of the roadmap and aims to reach, the micro process can be established, which concerns the agenda of the workshops.

Assessment of the customization literature

The T-Plan approach offers a way to customize TRM to the specific needs of the organization by considering manifold aspects that may vary with the organizational context. However, although very prescriptive in the development of the roadmap´s architecture, it lacks an elaboration how to customize the roadmapping process. Phaal et al (2004) state that the process depends on the architecture, but they do not explain how to derive the process from it. Thus, it seems that there

[7] Main source (if not mentioned differently) is: Phaal, Farrukh, Mills, et al. (2003)

is still gap in the literature about how to come up with the respective necessary process activities for developing a roadmap based on the customized roadmap architecture.

2.1.4 Implementation of Technology-Roadmapping

The literature of TRM implementation is not as comprehensive as the literature about roadmapping processes. The scope of implementation varies and is differently defined by authors. For some authors, implementation is restricted to the initial execution in the subject organization. For others, also the integration into the organization´s system belongs to the implementation process.

In the literature, there are two main parties, Phaal et al. and Gerdsri et al., who covered the entire scope of TRM implementation, and who respectively published several studies about it. Phaal et al first published their "T-Plan" in 2001, offering a fast plan which enables organizations to easily start with technology-roadmapping. The research from Gerdsri et al builds on that work, making it complementary by focusing not only on the initial implementation but also on the final integration into the organization´s system.

Implementation with the T-Plan (University of Cambridge)[8]

Some other parts of the T-Plan have been already introduced in the process- and customization section. The "T-Plan fast start approach" has been developed and applied in multiple companies from multiple industries in the 2000. One of the main aims for the researchers is to support the start-up of company-specific TRM processes, giving organizations guidance on how to initially implement technology-roadmapping.

The implementation process consists of three phases, namely planning, roadmapping workshops in which the TRM process is embedded, and roll-out (see figure 5).

In the planning phase, the objectives of the business with respect to the process are set and articulated, and the TRM process is customized to the specific objectives and the individual context of the organization. Ownership of the project and the roadmap are clarified and a project manager is determined. Finally, the TRM process is planned and a schedule is set up.

The second phase, roadmapping workshops, consists of two main parts. There is the standard approach for a product-technology roadmap, which has four subsequent workshops, structured

[8] Main source (if not mentioned differently) is: Phaal, Farrukh, Mitchell, & Probert (2003)

by the business aspects that are to be linked in the TRM process (as explained in section 2.1.2).And there is a customized approach to adapt the T-Plan to other, broader applications (as explained in section 2.1.3)

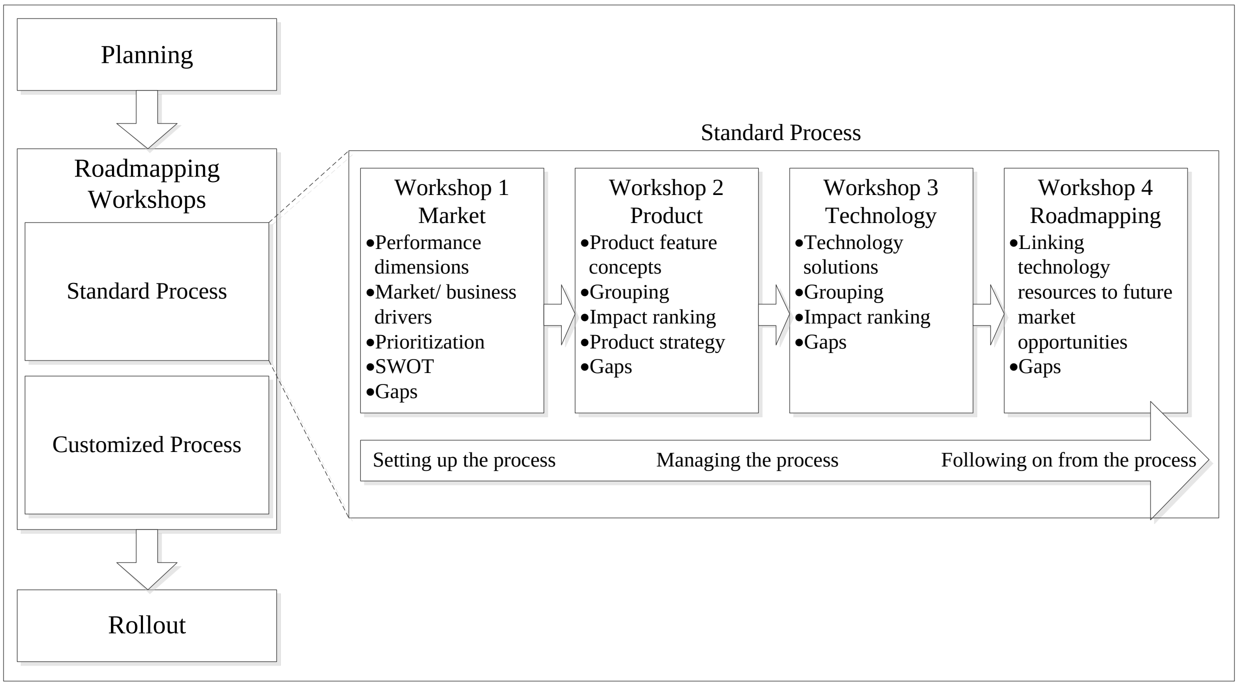

Figure 5: The complete T-Plan - three phases of implementation, including the TRM process[9]

In the third phase, the implementation of the roadmap takes place, as well as the final integration of TRM into the organizational system.

Implementation as a change process (Gerdsri & Vatananan[10])

People, processes and data are the most critical factors to a successful initiation and implementation of TRM (Nathasit Gerdsri & Vatananan, 2007, p. 1577). Highlighting the importance of people, the authors set the individuals´ roles and responsibilities as a major focus for the implementation process.

The authors start by defining three phases (i.e. initiation, development, and integration) in which they split the implementation process. The purpose of the first phase, initiation, is to gather and disseminate information that is used in later stages. The team is formed and is made familiar with the technology-roadmapping approach, and ground rules for team participation are set. After the basics are dealt with and agreed on in the official kick-off, the TRM process is to be customized

[9] Source: Phaal, Farrukh, Mills, et al., 2003
[10] Main source if not mentioned differently is Nathasit Gerdsri & Vatananan (2007)

and key stakeholders are approached to get them buy into the initiative. Having the right momentum, the first workshop can be planned and organized.

The second phase is mainly about data collection and analysis. Data is collected internally and externally between the workshops. The workshop then fulfils the function to bring together the team members, so that the collected information can be analyzed and knowledge can be shared, transferred and created.

For those organizations who want to assimilate the TRM process into the organizational system, instead of developing a one-time roadmap, go beyond the second and enter the third phase. The purpose of this phase is the integration of the TRM process as a continuous process into the existent, ongoing business operations.

After having defined the three phases, Gerdsri and Vatananan conducted research with respect to the dynamics of the key players and their contributions in the implementation process. They defined the key players and analyzed their roles and contributions in these three phases at successful TRM implementation projects.

Thereafter, Gerdsri and Vatananan integrated all their previous work about TRM implementation and combined it with change management literature (Nathasit Gerdsri, Assakul, & Vatananan, 2008). With the help of Prosci´s ADKAR model (Hiatt, 2006), activities are identified that prepare the individuals for change coming through the implementation process. Kotter´s (1996) eight stages of change are used complementary to identify further activities to manage the whole implementation process. The result is an activity guideline which should increase the probability of a successful TRM implementation (see table 1 for the activities).

Stage of TRM Implementation	Action Plan Supporting the three-stage TRM Implementation Process
Initiation (phase I)	• Understand the value of applying TRM in the organization • Build awareness of why TRM implementation is needed • Discuss the details of TRM concept • Raise urgency of why TRM implementation is immediately necessary to all participating members • Develop a vision, objective, and scope of TRM implementation for the organization • Set the plan to roll-out TRM implementation • Gain acceptance and sponsorship from top-management • Communicate the vision for the buy-in and support from key players • Form a working group responsible for activities related to TRM implementation

	• Provide the fundamental concept of TRM to all participants • Prepare all participants to be ready to implement the TRM process • Training sessions may be provided • Customize the generic TRM process to fit with the organizational setting
Development (phase II)	• Plan and organize a series of workshop sessions to develop a roadmap • Allocate responsibilities to each individual in the group as well as set up ground rules for the group participation • Maintain the momentum and energy from all participations throughout the TRM development process • Remove barriers blocking participants from carrying out their TRM activities • Conduct debriefing and review sessions
Integration (phase III)	• Consolidate roadmaps into one master roadmap (if needed) • Establish the procedures to review and revise a roadmap so that a roadmap can be kept alive • Integrate TRM process into organization's existing processes • Transfer ownership of the process to the proper group of people

Table 1: Activity guideline for the implementation of TRM[11]

Assessment of the implementation

To begin with, the two approaches overlap to a high degree. This can be easily explained, since Gerdsri builds on Phaal´s structure and content. Phaal et al cover the whole implementation process from linking of the business needs and objectives in the planning phase till the final integration into the organizational system in the roll-out phase. However, the focus is clearly set on the roadmapping workshops and less on the first or the third implementation phase. Thereby, they offer an approach that elaborates on the TRM process, whereas the TRM process represents a micro process embedded in the macro process of the actual implementation. Moreover, the approach includes an explanation how to customize the TRM process if the purpose is different from a product-technology roadmap. But elaboration of the TRM project and process planning and the final integration is neglected.

Gerdsri and Vatananan elaborate more on the planning and integration phase, and set a major focus on the human factor in all three implementation phases, which complements Phaal´s approach. Furthermore, they combine two complementary change management approaches, which results in a very precise list of activities to follow in order to have a successful implementation.

[11] Adopted from Nathasit Gerdsri et al. (2008)

2.2 PROJECT-DRIVEN ORGANIZATION

In the introduction, it is explained that the project-driven character of an organization comes from the complex nature and the associated customization of products. The effects from that situation on the organization are manifold and best captured by Hobday (Hobday, 1998b; 2000 & Hobday & Rush, 1999). He explored the character of "complex products and systems (CoPS)" and their effects on the organization.

The complexity in products comes from the number of customized components, the breadth of knowledge, and skills required and the degree of technological novelty, among others. Hobday (1998b) developed a measurement list to determine product characteristics and their complexity (see appendix A). He further argues that the complex nature of a product is determinative for the organizational form, coordination, and innovation processes of an organization; and that these aspects differ from mass-producing organizations.

Complex products are mainly produced in projects and small batches, customized for individual users. The optimal organizational form is the project-based firm, since it can be adapted to the demands of each project and each major customer (Mike Hobday, 2000).

Producing complex products has an effect on the innovation processes in the sense that innovation takes place during the project with a high involvement of the user, which means that the diffusion takes place at the same time as innovation. The focus of innovation lies on product design and development, and the deep and simultaneous broad knowledge needed to cope with these short-term, reactive innovation processes is embodied in the employees. The tacit nature of the knowledge and the project character make it difficult to manage knowledge and thus to realize effective organizational learning. (Mike Hobday, 1998)

Because of the complex nature, such products have different coordination needs. With increasing complexity, uncertainty and cost, coordination becomes more difficult. Dependent on the complexity of the product or system, the project requires the creation of multi-firm alliances for innovation and production, leading to a (temporary) network of organizations for the respective project. (Mike Hobday, 1998)

The market environment of CoPS producing organizations is described by Hobday as a B2B market with a duopolistic structure. The prices are negotiated for each single transaction.

Governments and regulator often have a high stake, which leads to many regulations and other control mechanisms. (Mike Hobday, 1998)

To conclude, the complex and tailor-made characteristics of the products makes an organization project-driven. This has many consequences. Since the demands of the customers are very specific and do not become apparent until an order is placed, an organization becomes dependent on the orders. This dependency has an effect on the organizational form, the coordination of processes and the innovation processes, which have to be considered when customizing the TRM process and the implementation.

2.3 REQUIREMENTS FOR TRM IN PROJECT-DRIVEN ORGANIZATIONS

By matching literature from the sub-chapter about project-driven organizations with the literature about TRM, requirements for TRM in project-driven organizations can be identified. These are presented in the following, separated by requirements for the TRM process and requirements for the implementation.

Requirements for a TRM process

The first requirement concerns the market drivers. The market of project-driven organizations tends to be highly regulated and politically influenced (Mike Hobday, 1998). This happens for a number of reasons, for instance, for safety or standard reasons, or to prevent monopolistic abuse. These external factors influence innovation and have to be considered as important drivers in the upper layer.

Another requirement addresses the production. Since complex products are individually developed and tailored and produced in projects or small batches, the product features, product technologies and production are interdependent (Michael Hobday & Davies, 2005; Mike Hobday, 1998b). For an appropriate roadmap, therefore, production (planning) and the linkage to product technologies and product features should be considered.

One the most challenging aspects for a TRM process in a project-driven organization is the general tacitness of knowledge. Breadth and the depth of knowledge required in a project, innovation that takes place during the projects, experience accumulated in the experts of the respective fields, and the project character itself with the general challenge for organizations to manage organizational learning from project to project are the reasons for knowledge being rather tacit than explicit (Mike Hobday, 1998). Whether explicit knowledge is preferable over tacit knowledge is still in debate (Prencipe & Tell, 2001). But at least the knowledge needed to develop the technology roadmap must be tapped into, which makes the importance of people/experts so central. In order to tap into the relevant tacit knowledge and make it explicit via the roadmap, the experts in the organization, who carry the tacit knowledge, must play a central role in the entire TRM process. A workshop-based approach seems therefore the optimal solution.

Prevailing in project-driven organizations is a short-term view. Since complex products are highly customized, the (specific) needs of the customers often become clear with the order inquiry (Mike Hobday, 1998). A long-term view is difficult, since innovation then happens on the project, triggered by the immediate needs of the customer. Additionally, the further the look into the future, the more uncertainty and risk appears, especially in project-driven organizations (Mike Hobday, 2000). In order to reduce uncertainty, a long-term view is necessary to compensate for the downsides of short-term resource allocation.

Requirements the TRM implementation

When it comes to the implementation, one requirement is of similar importance as it is for the TRM process, namely the involvement of people. As explained above, it is of high importance to have the tacit knowledge as input for the TRM process. Additionally, the initial implementation is a change process for the organization. For the change process to be successful, acceptance and involvement of the organizational members is of a high importance in all phases (Kotter, 1995; Nathasit Gerdsri et al., 2008).

But not only is the involvement of people/experts important, also the top management plays a critical role (Kotter, 1995). Assimilated by the project-driven demands, the top management tends to have a short-term view, and allocation of resources is mostly determined by the immediate customer needs (Christensen & Bower, 1996). However, TRM is a process in which a long-term perspective is needed and developed. This demands openness in the top management for long-term thinking in the beginning of the TRM implementation, since support from the highest hierarchical levels is vital. It is vital not only for the success of the whole process, but critical to remove barriers of the innovation project (e.g. enough resources) in the first place (Gemünden, Salomo, & Hölzle, 2007). Long-term thinking is also vital when the first roadmap is developed and ready to be ingrained into existing business processes. Due to high strategic relevance of the roadmap, it is up to the top management in how far they refer to the results of the TRM process. If still a short-term perspective is prevalent on the top floor, decisions and allocation of resources may be still made for the short-term, order-specific, customer-driven issues. Thus, top management´s understanding, acceptance and adoption of a long-term perspective is essential, which is the reason why they should be involved in the planning and the integration phase of the implementation.

The third requirement addresses the integration of the TRM process in the existing systems and processes. Due to project character and the project structure of project-driven organizations, organizational learning is rather problematic (Michael Hobday & Davies, 2005). As a consequence, valuable input for the roadmapping process can go lost, if, for instance, lessons learned, ideas or supplier information about future technological developments are not made explicit and codified for the next TRM process. Therefore, especially in project-driven organizations, the TRM process must not only be embedded into central business planning and strategic processes, but also linked to project processes. Particularly, the customer projects yield many opportunities to gain input for the roadmap, since these trigger mostly the innovation processes, where, for instance, employees gain insights into developments of suppliers and other partners.

Backed-up with the insights from the literature review and the linkage of theory, the next step is to develop an initial TRM approach for a project-driven organization.

3 Development of the Technology-Roadmapping Approach

Underpinned by the results of the literature review, the TRM approach for project-driven organizations is designed in this chapter (see also appendix B). In the first sub-chapter, the precise methodology for the design phase is explained, followed by the result in form of the TRM approach in the second sub-chapter.

3.1 Methodology

The expectation for the methodology is that it should enable the development of an appropriate TRM process for project-driven organizations. There may be many approaches available, from which only a limited amount makes sense given the boundary conditions. The set-up and schedule of the project at Siemens are such conditions, as well as the limited resources and time available for the master thesis. Another condition is the requirement to have theory and expertise incorporated.

One of the viable approaches meeting these conditions is the case-based action research methodology applied by Phaal et al in their research program, in which they developed and customized dozens of roadmap processes (Phaal, Farrukh, & Probert, 2004a). Since action research covers a large variety of approaches (Eden & Huxham, 1996), and the exact methodology of Phaal et al is not disclosed, another approach qualifies to fulfil the expectations. This approach is van Aken´s business problem solving circle (van Aken et al., 2006), which is very similar to case-based action research, and has some advantages. First, a strong theory-orientation before the actual implementation serves as strong foundation. Second, it is appropriate in the context of a change process, since the involvement of experts is a central aspect of the problem solving circle and vital in the context of change processes. Thirdly, it can be easily embedded in the already existing project schedule of Siemens SM, and is feasible given the available resources not only for Siemens, but also for this master thesis.

In the first step, van Aken states that it is important to build a theoretically correct design. Thus, with reference to the previous chapter, the TRM literature serves as the theoretical basis for the TRM approach to be developed. Phaal et al´s T-Plan is – as explained in the literature review – the best option available for the TRM process and its customization. With respect to the design of the TRM process implementation, a combination of Phaal et al´s and Gerdsri et al´s work is used. Therefore, the main task is to customize the T-Plan and implementation plan to the specific requirements identified in the literature about project-driven organizations (cf. section 2.3).

In the second step, according to van Aken, the theory-based TRM approach is to be evaluated and improved in iterative steps. Additionally, the process needs to be further customized to Siemens´ needs. According to Gerdsri et al (2007), the customization is an important step in the initiation phase of the implementation, where the involvement of the entire TRM project operation team is essential. A group meeting is therefore ideal to verify the TRM approach; hence, this is where the first iteration of the evaluation is done.

At this team meeting, the approach of the TRM process and the planning for the implementation are presented. The group of experts, who make up the TRM operation team, consists of managers from the respective business areas (marketing/sales, product development, engineering, production) and representatives with special functions (i.e. experts for relevant, central technologies; project management experts; sales representative for important business areas). The group has the competence to discuss the effects of a project-driven organization from different perspectives and to bring valuable input from their areas. Furthermore, an external consultant with experience in TRM accompanies the project. After the presentation of the initial planning, the approach is open for discussion and evaluation. Comments and remarks from the group are discussed and documented. After this meeting, the group should have a better understanding of the approach and will have given valuable inputs for the improvement of the approach. Based on the remarks and comments, the TRM approach is adjusted.

The project planning of Siemens even allows a second iteration, which improves the quality of the design according to van Aken. This iteration is done at the official kick-off meeting for the project, just before the actual start of roadmapping. Again, all the above-mentioned experts are present. A main part of the kick-off is devoted to methodology, which allows discussion about the adjusted TRM approach. The procedure is equal to the first group evaluation. Of course, again the feedback is documented and processed in order to adjust the TRM approach.

The development process – as described above – is presented in more detail in a result-oriented documentation in the appendix (see appendix B). The outcome of the entire procedure, an appropriate TRM approach for project-driven organizations ready to be implemented, is presented in the next sub-chapter.

3.2 Results – The Technology-Roadmapping Approach

In this section, an initial answer to the two research questions is given. As a result of the design process, the initial answers are condensed in a TRM approach, consisting of the TRM process and the implementation activities to be followed. (For the stepwise development leading to the results, please confer Appendix B)

The roadmap

The roadmap to be developed is a two-dimensional product-technology roadmap, consisting of the time dimension on the horizontal axis and five layers dividing the vertical axis (see figure 6).

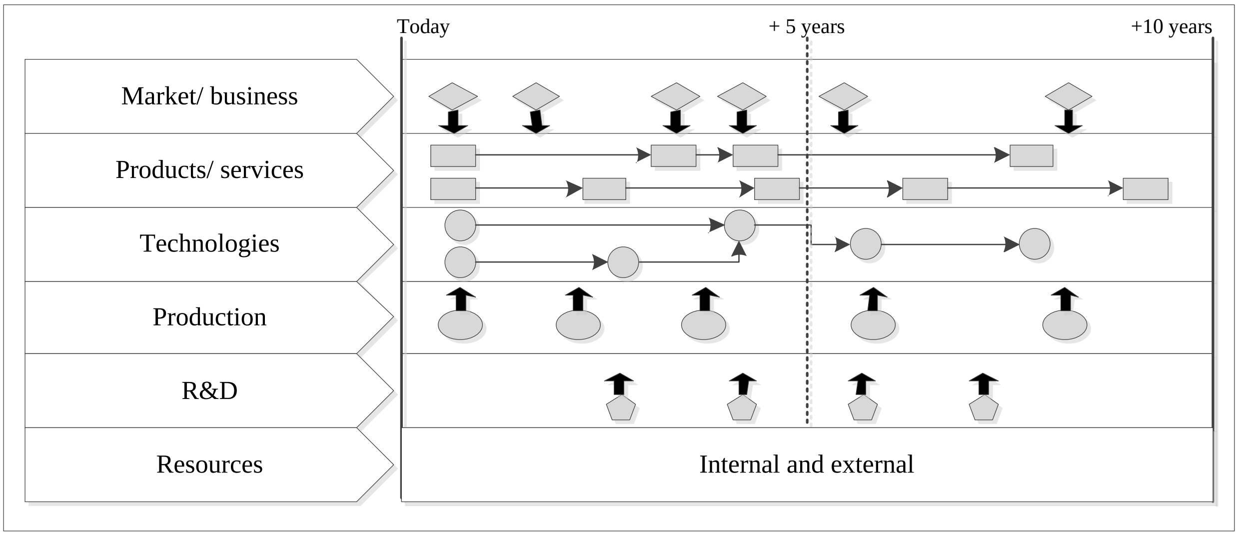

Figure 6: Product-technology roadmap prior to implementation

The time horizon to be covered is the next ten years, displaying therefore the short- and the long-term view of the different layers. The layers represent relevant business processes, which are to be inputted and linked during the roadmapping process. In the upper layer the market information is displayed. The lower layers are products/services, technologies, production, research and development, and resources respectively.

The roadmapping approach

The implementation consists of three phases (see figure 7). The first phase is the planning phase, where the roadmapping is prepared. The second phase is the TRM process, where the above-described roadmap is developed. In the third phase, the integration into the organizational system takes place. All three phases build on each other, and are to be followed consecutively. The details of each phase are elaborated in the following.

Planning (Phase I)

The purpose of the planning phase is to prepare for the main phase, the roadmapping process. Preparation is essential in the case of the initial implementation, since such an implementation constitutes a change process. Therefore, eight milestones are to be reached before the roadmapping should start (see figure 7).

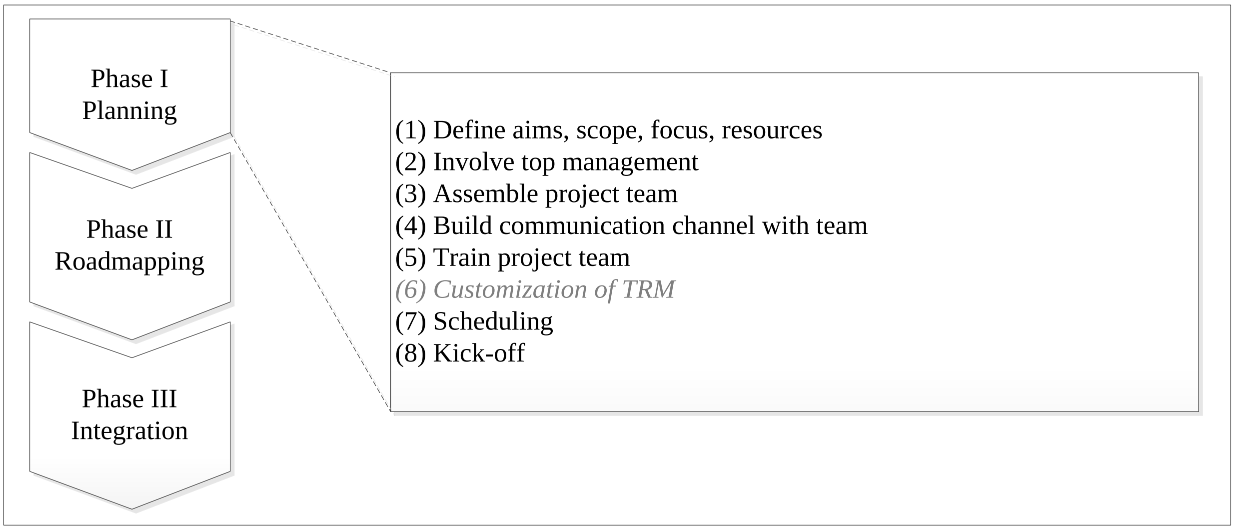

Figure 7: TRM implementation phases, detailed view of phase I

The first thing to do is to define the outer boundaries of the project, which includes the aims of the project, the scope and focus of TRM, and the resources necessary to finish the project and reach the project aims. The context of the TRM implementation must be clear, and a reliable first picture must be framed about the efforts to invest.

In the next step, the top management is confronted with a request launch the project. The main goal is to gain acceptance and support from them, since resources are needed and the outcome is of high strategic relevance. By gaining support, organizational barriers are easier to overcome.

The team plays a fundamental role in the implementation. It consists of experts for the affected business areas, the project leader and an external consultant as an objective mediator with experience about TRM methodology. After having assembled the team members, it is very helpful to determine communication channels to all of them to assure direct and immediate communication. This makes coordination easier, and improves the dissemination of important information, such as intermediate results, appointments for meetings, and specifications about TRM. The latter one is especially important in the planning phase, since each team member must be made familiar with TRM. The customization is optimally done in team work. However, this requires the team members to be familiar with the method and its purpose.

Note: The customization constitutes an important milestone in the planning phase, since the TRM approach has to be adapted to the organizations specific needs. However, this TRM process is designed for a project-driven organization which wants to develop a product-technology roadmap. This means that some aspects are fixed, as they fulfil essential requirements for a project-driven organization. This concerns the roadmap layers and some process activities in particular (cf. 2.3). If any aspect of the TRM approach is changed, then it is important to change only those non-relevant aspects. Otherwise, the TRM process would lose in suitability for the project-driven organization. What could be changed, for instance, is how far the organization wants to look into the future (i.e. the horizontal axis).

After the customization, the entire project can be scheduled to assure team members´ involvement. The meetings and workshops should be announced early enough, and the respective input can be scheduled so that every member can align the demand arising from the project with his/her other duties. This is suggested to handle in a kick-off meeting with all team members, where the entire planning for the roadmapping is presented and – if necessary – discussed and adapted.

Note: The planning phase is already finished at this point of the master thesis. All milestones were reached, which means that the roadmapping phase can begin.

Roadmapping (Phase II)

A workshop-based roadmapping is the cornerstone of the TRM approach. To fill and link the six layers of the desired roadmap, six workshops with respective milestones are planned. The workshops are labelled market, product, technology, production, R&D and resources (see figure 8).

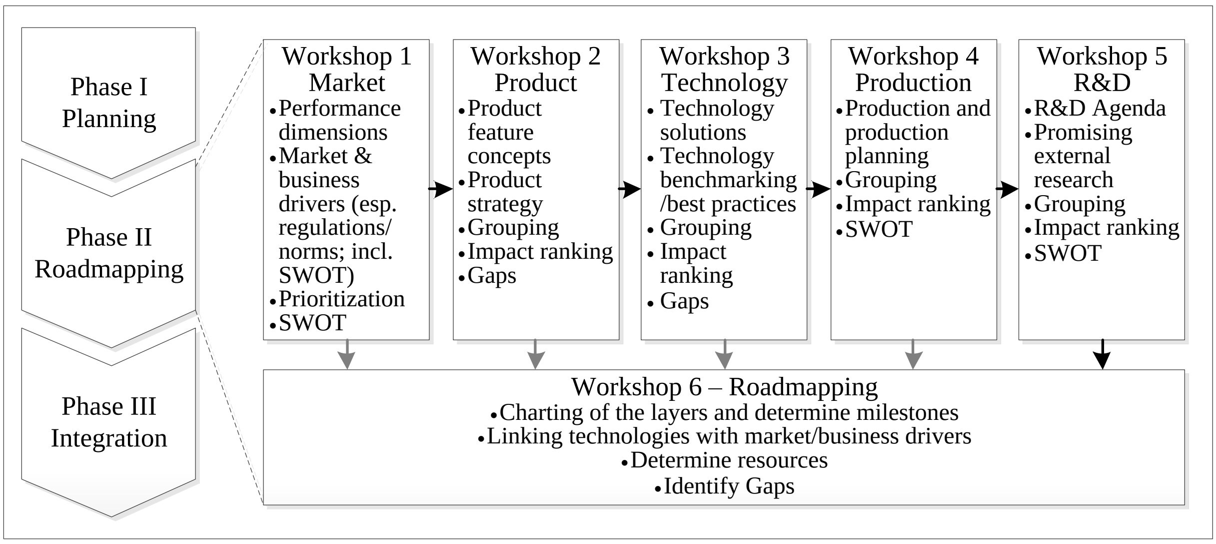

Figure 8: TRM implementation phases, detailed view of phase II

Workshop procedure

Each workshop has a preparation phase and a post-evaluation (see figure 9). The preparation should guarantee that the necessary information input is given for the respective workshop. Therefore, a questionnaire is developed for each of the first five workshops, whose questions are based on the milestones to be fulfilled. The questionnaire is sent to the project team with the directive to give comments. Based on the comments, the questionnaire is adjusted and given to the “expert(s) of the workshop”. The “expert(s) of the workshop” is/are the organizational members whose information input is asked for. For the first workshop, for instance, this is the marketing manager.

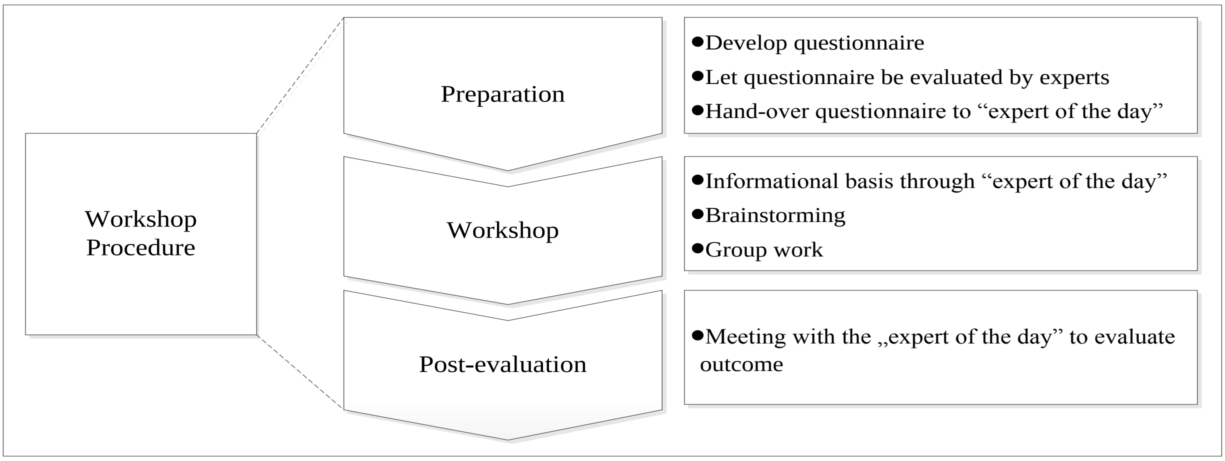

Figure 9: Workshop procedure for the first five workshops

In the first five workshops, the “expert of the day” starts with the informational basis by trying to answer the questions. After the information input, the brainstorming method is used to enrich the informational basis by the tacit knowledge from the experts, so that the respective content for the roadmap can be collected and documented. Thereafter, further group work leads to the fulfilment of all milestones of the respective workshop.

The post-evaluation is done with the core team (project leader; project leader assistant) and the “expert of the day” in a meeting within a few days after the workshop. The goal is to verify the outcome. This is critical, since one workshop´s output is the next workshop´s input.

Workshops

In the first workshop, the upper layer´s content is generated. It starts with the identification of performance dimensions by which the organization is judged (and can be judged in the future) by its customers. Next, the business and market drivers affecting those performance dimensions are to be identified and collected in order to prioritize these. Of special relevance are external drivers like regulations and political trends. Finally, a SWOT analysis for the market perspective is conducted and gaps identified.

The second workshop links to the prioritized market and business drivers. The goal is to identify product feature concepts that can satisfy the drivers. Therefore, the product feature concepts are to be derived and grouped. The product strategy gives more indications for possible product features, especially for the future perspective. Finally, the product features are linked to the drivers in a two-dimensional grid. Intersections of the drivers and product features are rated in order to determine the impact. Finally, gaps are sought.

In the technology workshop, technological solutions are identified, grouped, and linked to and rated against the product features. Therefore, technological solutions are derived from the product features, which is a market-oriented approach.

The fourth workshop is about production. In project-driven organizations, the production and the products are highly interdependent, which is why the production is important to consider in the roadmapping procedure. Here, aspects that lead to the realization of product features are identified. Finally, a SWOT analysis for the production is conducted.

The fifth workshop deals with R&D that realizes technologies and production, therefore connecting to the outputs from workshop three and four. The existing R&D roadmap is presented, as well as promising external research. Then, in a grid, those measures are linked to the technologies and rated in impact. A SWOT analysis with respect to R&D completes the workshop.

The final workshop is dedicated to the roadmapping. In the first step, each layer is charted by entering the outcomes from the respective workshops. Milestones can be determined. Based on the impact ratings from each workshop, all business areas are already connected to each other. The market side can now be linked to the technologies, and different priorities and routes become apparent. Based on the main links, resources can be allocated in order to support the development of the technologies. Furthermore, information and development gaps become obvious.

Note: The roadmapping process is designed for the initial implementation into the project-driven organization. It is not feasible to follow the whole procedure of six workshops once a year. It would consume too much time and therefore resources. However, the roadmap should be updated regularly, which means that all of the activities should be repeated once a year. A solution is to compress the activities to two workshop days maximum. This is feasible, since most of the content and the linkages stay the same. Thus, the update is about the verification of the “old” roadmap and the integration of new information.

Integration (Phase III)

The integration is a very critical phase, since it induces actual changes in the organizational system and processes. Four milestones are defined for this last phase (see figure 10).

Once the roadmap is generated, the results must be integrated into the existing business systems and processes. Although the first roadmap may be not considered as complete after the first run-through, it very well represents a synthesis of what is currently known by the organization. Therefore, it is reasonable to use the roadmapping results for decision making.

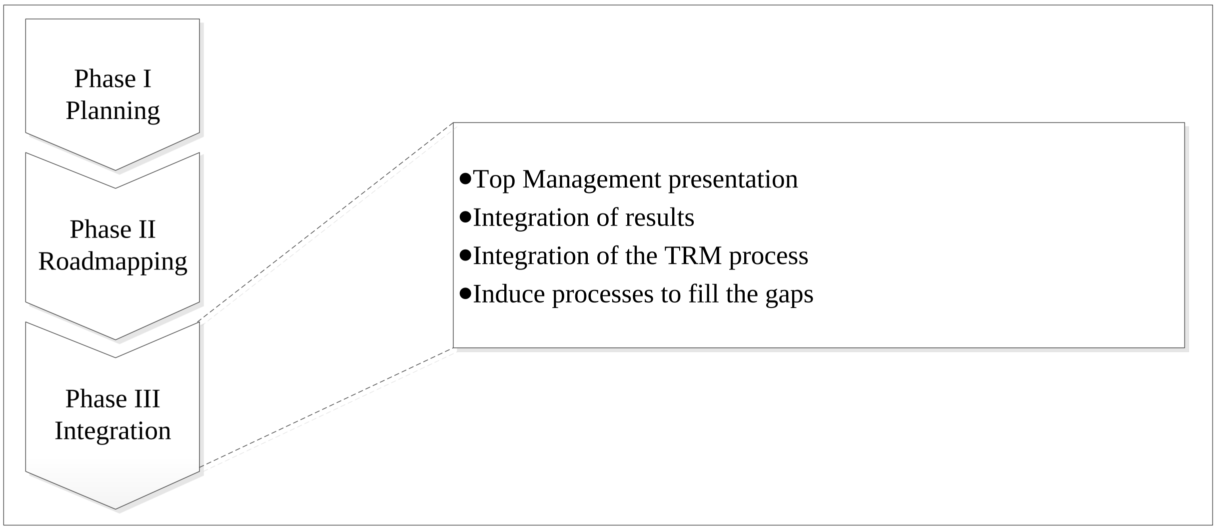

Figure 10: TRM implementation phases, detailed view of phase III

A second aspect of integration is to make the TRM process a continuous process. In most cases, the ownership is best transferred to the marketing department, or more precisely, to the product management. Once a year, the roadmap should be reviewed and updated in context of the existing business planning. Two workshop days must be enough to do so. Between the updates, though, data should be collected that will serve as input for the next run-through, making it a continuous process. Valuable data is generated and can be captured in the customer projects. Therefore, processes (e.g. project evaluation (written or group reflection); interviews with the project managers; etc.) need to be embedded to extract the necessary information from the projects.

In order to be allowed to integrate the roadmap and the process, a top management presentation can be pivotal. Since they are mostly not involved in each of the workshops, they must be made familiar with the entire process, the result, and the value for the organization. Ultimately, the executives decide for the allocation of resources and if/how processes are integrated. Moreover, they are the ones who will most likely use the results for strategic decision-making.

A final milestone is to induce processes to fill the gaps that were identified in the workshops. This may be, for instance, to alter other processes or to acquire information from external.

4 Evaluation of the TRM Approach

The implementation into Siemens´ organization constitutes a test for the developed TRM approach. But more than that, the implementation can lead to further improvements. As it will be explained, the process worked mostly well. However, sometimes, necessary changes have been made by the project team in order to proceed in the process and to successfully develop the roadmap.

This chapter is divided into three sections. The first sub-chapter is about the methodology for the implementation´s evaluation. In the second sub-chapter, strengths and weaknesses of the developed TRM approach are described per workshop. This especially includes weaknesses of the actual approach and the adaptations that were made during implementation. The third section is an overall evaluation, highlighting the strengths and weaknesses of the approach in retrospective. The weaknesses from this evaluation have not been fixed by the project team. They still remain to be solved for a better TRM approach and for the complete implementation at Siemens, which is dealt with in chapter 5 and 6.

4.1 Methodology

The goal is to have a thorough and relevant evaluation of the TRM approach, focusing on the strengths and weaknesses. For the final improvement and the recommendation for Siemens SM, rather qualitative than quantitative measurements of strengths and weaknesses are needed, which demands qualitative data collection and analysis methods.

Data Collection and Analysis

The strengths and weaknesses are presented in two separate, though complementing evaluations. The first evaluation, here called interim evaluation, reveals the strengths and weaknesses of the TRM process during the implementation. This is beneficial, since deviations from the process can be tracked, justified and presented per workshop. The measurement is conducted immediately in the workshop, revealing the strength, weaknesses and solutions encountered.

Data collection is based on personal observations. Notes about strength, weaknesses and solutions are made during workshops. These are comments, (missed) results, obstacles, intensive discussion points, deviations from the agenda and other issues that indicate a strength and/or weakness with respect to the TRM approach. After the workshop, these notes are transferred to and documented in a table (see appendix C). Besides the direct and immediate measurement, the validity is increased even more by referring to original project documents (i.e. workshop presentations; photos from the workshops; workshop and project documentation).

Note: Unfortunately, these original documents cannot be disclosed and published due to confidentiality reasons. However, to increase the validity, these documents have been used (see appendix C).

For the description of the interim evaluation, no complicated data analysis has to be applied. Due to the pre-filtered data collection, the results can be directly converted into text-form without threatening the validity.

The second evaluation, here called post-evaluation, is a retrospective measurement of the strengths and weaknesses. Taking into account the overall functioning, the project team reflects on the appropriateness of the TRM approach. This measurement is complementary to the interim evaluation, since the interim evaluation is about the encountered strengths and encountered and solved weaknesses, whereas the post-evaluation is about the overall strengths and unsolved weaknesses.

For the post-evaluation, two data collection methods are most applicable. To collect data from the entire project team, a feedback round is conducted in the end of the last workshop. Via an open question, the group is asked to evaluate the entire process by its strengths and weaknesses, considering the initiation (phase I) and TRM process (phase II). The mentioned/discussed strengths and weaknesses are noted down during the feedback round, and transferred to a table thereafter (see appendix D). For the evaluation, the points can be easily converted into written text, equal to the procedure in the interim evaluation.

To complement the post evaluation by a more sophisticated measurement, the two project-responsible Siemens employees are interviewed. Since they are the initiators of the project, responsible for the communication to the top-management about the project proceeding, and involved in all meetings (esp. preparation- and post-meetings), they can best point out the strengths and identify the weaknesses from a more global perspective. In face-to-face interviews after the last workshop, open questions are asked to receive the necessary data (see appendix E). The interviews are taped and transcribed (see Interview Transcript). Based on the written text, the strengths and weaknesses can be isolated (see Interview Transcript) and merged with the team findings from the workshop to formulate a thorough post-evaluation.

Validity, reliability and ethical considerations

Qualitative research does not carry the same connotations as compared to quantitative research (Creswell, 2009). Validation of qualitative data already occurs in the process of research. Creswell (2009) states that qualitative validity means that the researcher checks for the accuracy of findings by employing certain procedures. In this study, especially the combination of different data collection methods allows triangulation and therewith a validation of data. For the post-evaluation, personal observations through permanent involvement of the researcher in the project are constantly used to validate the data coming from the feedback round and interviews. In turn, personal observations to be made for the interim evaluation are supported by the project documentation, workshop photos and workshop documentation. Thus, constant comparison of the data from different sources improves the validity of the qualitative measurement.

Qualitative reliability indicates that the researcher´s approach is consistent across different researchers and different projects (Gibbs, 2007). Yin (2003) suggests a thorough documentation of the procedures undertaken in the data collection and analysis. Gibbs (2007) further suggests to double-check the transcripts for obvious mistakes, and to write memos to ensure that deviations can be traced. For this study, the research process, written data and the analysis are made transparent and are attached to the appendix, increasing the transparency and replicability. Transcripts are double-checked and to be authorized by the interviewees, so that reliability is maximized.

With respect to ethical aspects of the study, the sensibility of strategic relevant data is most important to discuss. To minimize conflicts, proper data management and safe transfer of data between the researcher and organizational members is practiced by using Siemens´ IT services. Furthermore, the researcher is well-informed about Siemens´s code of conduct and familiar with the handling of non-disclosure material, since he is employed by Siemens. This means for the information disclosed on this thesis, that the results presented from research are anonymized to such a degree that they comply with Siemens´s rules.

Another very typical ethical issue subject to most studies is the anonymization of respondents in research. In accordance with the two interviewees (i.e. the project-responsible employees), their initials and positions are disclosed. The interviews´ transcriptions are double-checked by them personally, and authorization for disclosure of the transcript is given. The identity of the project team´s members, however, is totally anonymized as well as the responses given in the workshops.

A final ethical aspect is the role of the researcher. On the one side, he accompanies the entire project at Siemens as an employee, which might lead to a subjective perspective. On the other side, there is the obligation and the quality of the researcher to stay objective. This potential conflict is minimized through two aspects. First, the methodology minimizes the subjective influence of the researcher. Thus, although the researcher´s role as a team member of the TRM project at Siemens might lead to bias in the research, the design of the research minimizes this effect. The usage of different data sources and data collection methods increases the validity through triangulation. In addition, a thorough documentation of the data collection and the subsequent analysis increases the reliability and transparency. Second, the general expectation from Siemens is to receive a critical and appropriate recommendation, which excludes the indication of a self-confirmative study. Moreover, it lies in the personal interest of the researcher to receive an objective outcome, namely an appropriate, critical and constructive recommendation for Siemens. This recommendation must be based on the implementation and thorough data collection and analysis, without being led by non-objective interest.

4.2 Results – Interim Evaluation

In this section, the evaluation of the implementation is presented per workshop. It demonstrates the strengths and weaknesses and the changes that were made during the process[12].

The market workshop started already with a first obstacle. Actually, the first group activity was to identify performance dimensions. However, the workshops participants argued that a differentiation is needed, since importance of performance dimensions varies with target markets. The diversity and heterogeneity of their markets made it impossible to identify and prioritize performance dimensions. That means that before performance dimensions could be identified, a pre-step had to be included. The solution was to define homogeneous market segments, so that performance dimensions could be identified and allocated to each market segment. This differentiation is necessary to display the heterogeneity of market requirements in the market layer of the roadmap. After the problem was solved, the workshop day continued without deviation from the original approach, and resulted in the identification of 15 performance dimensions from which nine business and market drivers have been derived and prioritized.

The second workshop was the smoothest workshop of all, without any deviation from the original planning. Product feature concepts have been identified very systematically. First, an

[12] Reference for this sub-chapter: Appendix C – Personal Observation (Documentation)

extensive list of product features has been collected, using the specification list for Siemens´ machines. In the second step, the list has been completed by brainstorming and in consideration of the product strategies. In the third step, product features that cannot be influenced or have simply to be accepted by them have been removed from the list (e.g. voltage of the electrical grid; protection specifications). After grouping, 17 product feature groups remained. In the final step, the product features have been rated in impact for each of the 15 performance dimensions.

Workshop three was the most challenging for the project team, though minor deviations occurred from the original approach. The complexity of the products and the resulting complexity in the technologies led to changes in the logical structure for subsequent workshop four and five, which are elaborated in the next paragraphs. In the preparation phase of workshop three, already more than 250 technologies have been identified. After grouping them (partly before, partly during the workshop), the project team ended up with a manageable number of 25 product- and production technologies, covering actual and future technologies (e.g. cooling technology; noise reduction technologies; lightweight design). This process had already consumed a considerable amount of the workshop, so that the benchmarking of technologies and the consideration of best practices from other industries has been handled rather tentatively. In the end of the workshop, the technology groups have been rated in impact for the product features, which resulted in initial prioritizations.

As indicated, the complexity of technologies led to deviations in logic for workshop four. The actual plan was to deal with the production in general in order to derive supporting measures for technologies and product features. In light of the developed technologies from workshop three, it did not seem to be logical for the project team to follow the planned activities. They decided that it makes more sense to focus on the in workshop three identified production technologies exclusively. Thus, workshop four became an elaboration of workshop three. The production technologies have been inspected in more detail by discussing sub-technologies of the technology groups. Therefore, the extensive list of 250 technologies from workshop three helped to allocate the necessary production technologies. As a result, 15 technologies were identified, for which the development of the coming ten years has been discussed. The most important milestones have been determined, linked, and top measures for the production have been derived with the help of the impact ranking from workshop three.

Workshop five was also subject to change, although not in the same magnitude as workshop four. In the same manner as workshop four was a detailed analysis of the production technologies, workshop five became an elaboration of the product technologies. The project team has dealt with 24 technologies, discussed the development over the coming 10 years for each of them, linked them, and determined the most important milestones based on the impact ranking from workshop three and the linkages. Deviation from the original approach is minimal, since the discussion of the technologies´ developments was based on the R&D agenda. Due to time pressure, the integration of external developments was coming too short. However, in the end of the workshop, this was not considered as a disadvantage by the project team, since their organization is leading in most of their technologies.

The final workshop, roadmapping, had its pitfalls simply because of the complexity that was tried to display on the roadmap. First, the market layer has been fed with major milestones for the respective market segments over the coming ten years. In the second step, milestones for product features have been placed in orientation to the market milestones. For the technology layer, the project team agreed that it is not appropriate to only display some main milestones. As a decision tool, it is important to display all technological options that were developed in workshops three to five. Only the linkages from the upper layer to the bottom layer should reflect the currently felt priorities.

Thus, the roadmap became rather complex in the technology layer, though allows to quickly alter the linkages in case of changing market priorities. What was coming short in the end was the determination of resources to support the technologies. The project team said that there are still too many important technologies to be developed for the current market focus. It is not feasible to plan the resources at this stage. It would take too much time in the TRM process, considering that more than 12 experts are present in the workshops.

As indicated in the original approach, the SWOT and gap analyses have been conducted and generated valuable information. Based on that information, the next run-through can be prepared and processes to fill the gaps can be implemented (as recommended in chapter 6).

To conclude the interim evaluation, one can say that the implementation serves as a third iteration in the design process for the TRM approach. When an obstacle became apparent, the competence of the project team enabled the fast and effective removal of the obstacle by adapting the TRM approach. These adaptations made by the project team become part of the final TRM approach as presented in the appendix (cf. appendix H).

4.3 Results – Post Evaluation

Undeniably, the TRM process finally resulted in a technology roadmap thanks to the constant evaluation of the project members in the course of the implementation. This does not necessarily mean that the process and the implementation were successful in all aspects. The following post-evaluation therefore sheds light into the strengths and weaknesses[13].

To begin with the strength of the approach, there is a strong agreement among the project members that the result and the process is good and fits to the situation of a project-driven organization. The process has functioned well, taking into account the changes that have been made in the course of the implementation. The initially set goals have been reached, which means that existent information/knowledge has been brought together and concentrated into a concentrated roadmap, that perspectives from different business areas have been aligned, and that the weaknesses and gaps have been identified. One manager said, that the discussion about R&D projects led to a common understanding about what they are good for, which brings them on the same knowledge level (cf. appendix F).

Actually, one of the main obstacles in process implementations like these is to receive the resources, to coordinate the project members, and to convince the project members to be involved in all session. But thanks to the structured approach, including the preparation and post-meetings of the workshops, the entire coordination has been smooth and well accepted by all stakeholders.

The involvement of the external consultant is seen as one of the strengths, too. Experts often drifted into extensive discussion. The consultant intervened in that situation and brought the attention back to the actual belongings. Furthermore, in case obstacles occurred in the process, experience in methodology helped to solve the problem.

The evaluation also revealed weaknesses, which can be consolidated into in two points. The first one is the missing of radical innovations. Nearly all stakeholders noted that the roadmap does not contain that many radical ideas. Although some alternatives have been discussed and brainstorming has been applied to identify radical innovations, the result was rather thin. But

[13] Reference for this sub-chapter:
- Appendix D – Post Evaluation (Project Team)
- Appendix F – Post Evaluation (Interview from 2012-06-04
- Appendix G – Post-Evaluation (Interview from 2012-06-07)

radical innovations are seen as an important aspect in building competitive advantages and should therefore be identified in such a roadmapping process.

The second weakness is the missing external perspective. In the process, neither benchmarking of technologies nor search for best practices has been done. The identified technologies are almost internal developments, therewith neglecting the external perspectives and developments. Since many processes and components are sourced from outside the organization, technological developments at suppliers would be important to consider in the roadmap, leading to valuable input.

Overall, the TRM process has been successful, fulfilling the initially set goals. Some weaknesses have been already corrected in the course of the implementation. Some weaknesses remained, as the post evaluation shows. In the coming chapter, the remaining weaknesses are addressed in order to improve the TRM approach for project-driven organizations and to give Siemens Special Machines a recommendation for their further implementation.

5 IMPLICATIONS

The evaluation of the implementation is valuable feedback to further improve the process. It is divided between two kinds of evaluations. The one evaluation consists of the changes already induced during the implementation. The other evaluation has been made after the sixth workshop.

The changes made during the project can become part of the TRM process for project-driven organizations. The advantage is that these changes were already tested in the implementation. The project team followed the adjusted process, and the result was successful. What can be said additionally is that the interim adaptations are not the cause for the identified weaknesses from the post-evaluation. As an implication, the interim changes can be adopted in the final TRM process (see Figure 15: Final TRM approach – phase II (TRM process)).

The post-evaluation has revealed two main weaknesses. These were neither addressed by the project team during the implementation nor solved so far in any way. One problem is missing radical innovation, the other a missing external perspective. In the following, it should be explained in how far these problems constitute real problems for project driven organizations, or if they are a specific request from Siemens SM. And, in case they are relevant for project-driven organizations, how can they be compensated.

Radical innovations

The situation is that several project team members criticized the final roadmap for its lacks of innovative ideas. They expected to have more radical innovations in the end of the process. This feedback now provokes several questions. First, are radical ideas important on a roadmap for project-driven organizations? Second, was the TRM approach supposed to process or produce radical innovations? And thirdly, in case radical ideas are needed on the roadmap, how can be the process improved to realize the integration of radical ideas?

According to Hobday (1998b), in project-driven organizations, innovation usually takes place on the project. Projects trigger R&D measures, which results to a great extend in incremental innovation since resources are allocated to customer needs. Furthermore, technology life-cycles are usually very long, lasting decades before the technology is replaced (Mike Hobday, 1998). The consequence is that the consideration of radical innovation comes too short. The focus is on the short-term, and an innovation imbalance towards incremental innovations evolves.

However, when developing a roadmap, especially the long-term perspective is of high importance to reduce uncertainty and risks in strategic decision making. Therefore, when looking into the future, the importance of radical innovations becomes apparent. This means for a TRM process in a project-driven organization, that radical innovation constitute an important aspect not to underestimate.

The proposed TRM process was not intended to focus on radical innovations, although it was implicitly expected to receive radical ideas as input from the different business processes. Basically, the focus has lied more on the market, as Phaal et al proposed in their T-Plan. Phaal et al do not differentiate between incremental and radical innovation in their T-Plan. They suggest tracking disruptive innovation as opportunities or threats, but own radical innovations are neglected, since the entire process is market-oriented. Following solely the market-oriented approach would lead to a primary mapping of incremental technological improvements, neglecting radical technological innovations and the product features and market requirement that could have been realized. Exactly this was the result of the evaluation.

A simple change can correct this weakness. After having done the actual market-oriented roadmapping from the market to the technologies (workshop 1-3), another session/activity is added to reverse the whole process. In this additional resource-oriented approach, first technological radical innovations are identified by applying creativity techniques like brainstorming. Thereafter, another brainstorming session is conducted to search for product features that could be realized or drastically improved with those radical product- or production technologies. Finally, the markets and drivers are identified that could be satisfied or served in a better way. By enhancing the market-driven by the resource-driven approach, incremental as well as radical innovations become content of the roadmap. This bi-directional approach delivers the full picture of technological options and compensates for the imbalance towards incremental innovations.

External developments

In the implementation, the focus was mainly on internal developments, almost ignoring technological developments outside the organization. This feedback was given several times by some project members. Other project members opposed that it is not easy to integrate the external perspective. They gave two main reasons for that. “First, if you are technology leader, whom do you want to observe? You are leading, not the others. Second, if someone is further than you in development, these projects would be top secret and you would not find out anything about it."

But the questions here should be similar to the discussion about radical innovations. First, is the external perspective an important aspect in a TRM process for project-driven organizations? Second, was the TRM process designed to integrate the external perspective? And lastly, how can be the process improved to integrate external developments in case they are important?

According to the definition, project-driven organizations are producer of complex products. With respect to complex products, Hobday (1998b) states that the complexity of the products and the resulting complexity of the knowledge leads to innovation and production networks. Suppliers and other partners form theses networks make up the necessary capabilities and capacities to develop and produce complex products. Said differently, only such networks allow building complex products. And, the more complex the products, the bigger the network needed to cope with this complexity.

Innovation and production consequently do not happen only within own organizational boundaries, which means that input from the network must be considered for an adequate roadmap. It does not mean to track the "top secret projects" of competitors, but to integrate planning from other partners. This includes, for instance, market projections, product developments, incremental and radical technological innovations from suppliers and institutions. For example, a radical technology from a component or material supplier could lead to an improved way to realize a certain product features of my own product.

What becomes obvious in the discussion about production and innovation networks is the absolute need to integrate information input of external developments in light of radical innovations. When (potential) relevant innovation takes place outside the firm, and radical technological developments are needed as input for the long-term perspective of the roadmap, then the network information about future radical developments constitutes essential input for the TRM process. In contrast, incremental improvements and evolutionary developments can simply be extrapolated – radical innovations rather not.

Information input from the innovation and production network is not explicitly mentioned in Phaal et al´s or in the here developed TRM approach. Partnerships are placed in the resource layer at the very bottom of the roadmap as a mean to realize the planned technologies, but not as an informational source. To improve the TRM approach in accordance with this requirement, it would be essential to know in how far certain partners expect technological innovations in the future, and to use this as input for the TRM process.

One way to integrate such information is to simply add that activity to the TRM approach. It can be assumed that such information is somehow existent within the organization. The inherent character of a network is that many interfaces exist between the organizations, and that exchange of information takes place. Therefore, at least the own sales people and production managers are well informed about the situation of their network partners. Interviewing them as a preparation for the workshop(s) would allow to collect the necessary information and to process it in the workshop. In case the interviews are not that helpful, a little research directly at the network partners can bring complementary information. If this is also unsatisfying, this point is declared as a gap in the TRM process and is to be solved by implementing new business processes. At least, when updating the roadmap in the next run-through, external information can be considered.

To conclude, the weaknesses identified through the post-evaluation are legitimate and their solution become part of the final TRM approach (see appendix H). Radical innovations should be part of the roadmap, as well as external developments. The question is always if the process is then still manageable, or if it becomes too complex and time consuming. In a change project – and that is what an initial implementation of a TRM process is – it is essential to keep the process simple to avoid barriers and resistance. It is important to not spend too many resources, and to keep the project manageable. According to the discussion above, radical innovations and external development are important. But if the implementation fails because the process becomes unmanageable, the entire process is worth nothing. That is why Phaal et al and Gerdsri recommend following the process until the end. When an informational gap becomes apparent, they suggest closing that gap afterward by implementing the necessary business processes.

Thus, if it is too time-consuming or extensive to indentify and integrate radical information and/or external developments, then finish the first roadmap simply with the information at hand. The critical aspect about the first roadmap is the implementation, not completeness. Gaps can be closed in the second run. The true value of roadmapping becomes apparent anyway after a few years of application and several iterations (Phaal, Farrukh, Mills, et al., 2003).

6 Recommendation for Siemens Special Machines

The evaluation reveals that the TRM process is seen as successful. However, there is still a gap between what the final design proposes (cf. appendix H) and what the project team has done so far (cf. section 4.2 and 4.3). This gap exists due to three reasons. First of all, Siemens SM is currently still in the middle of phase III, which means that the final integration is not yet finished, leaving some open activities to follow from the original TRM approach. Secondly, the improvement of the TRM approach based on the post-evaluation leads to the integration of new activities, which have not been started yet by the project team. Finally, as described in the evaluation, some activities from the original approach had been neglected during the implementation.

Finish the integration

The developed roadmap is accepted by all stakeholders. Therefore, it is recommended finishing phase three of the implementation before going backwards to catch up with the undone process activities. The final integration is an essential part of the entire process, because the roadmapping results, as well as the process itself, are to be embedded into the organizational systems and processes.

The first step is the integration of the roadmapping results. The usage of the roadmap is to facilitate technology management. More precisely, the roadmap supports long-term strategic decision making in business strategy formation by linking the market-projection with the technological resources. Furthermore, based on strategic decisions, R&D projects can be initiated so that the technologies are readily developed when they are needed. Thus, the roadmap should be linked to business strategy formation, as well as to the planning of the R&D department of Siemens SM.

The second step is the integration into existing processes. Siemens´ internal processes propose to integrate the TRM process in the yearly product portfolio planning procedure. Therefore, the ownership is best transferred to the marketing department, where the product portfolio management is located at Siemens SM. The roadmap is then reviewed and updated on a yearly basis, which accords Phaal et al´s (2003) recommendation and is practiced by the majority of the firms. Updates do not need the extent of six workshops, though the old roadmap should be reviewed and new information integrated. Probably two workshop days are enough for that.

In the last step of the integration, the identified informational gaps are to be closed. This is a task to be finished by the beginning of the next roadmapping process (i.e. review/update). Thanks to the SWOT and gap analyses, the weaknesses of the business areas and the informational gaps are known and well documented. Aware of the weak points, existing processes are to be adapted or implemented so that the gaps can be closed. Examples for such processes are given in the next section, where it is about informational gaps that were identified in the post-evaluation.

Open activities and gaps to fill

As the post evaluation shows, there are some undone activities which led to informational gaps. These activities are the identification of radical innovations, input of external developments and allocation of resources to technologies. But, as explained above, it does not make sense to enforce finishing these activities for the first roadmap. The primary focus should lie on the finalization of the integration, not completeness. However, processes must be adapted or implemented to fill the gaps until the next run-through.

There are many possibilities to identify radical innovations, but the most common approaches are creativity technique in expert groups. Thus, one proposition is to conduct regular creativity sessions (e.g. brainstorming) in the R&D department. Cross-fertilization of the experts from different technological areas may produce new ideas how to realize certain product features.

Information about external developments can also be collected in many ways. But all measures have one common goal, which is to provoke knowledge spillovers of valuable information for the next TRM process. Such information could be tapped into by conducting workshops with suppliers, or by starting collaborative R&D projects. There are many approaches, and they may vary with the partner from whom information wants to be gathered. With some suppliers, open discussions about their R&D projects may be appropriate. With other partners, indirect methods (e.g. common projects with institutes; collaboration in research) may be the best way to get insight into these organizations. Another source may be other Siemens organizations, or even central R&D departments. It does not even need to be the same industry. For instance, material science is an essential aspect of Siemens´ machines. Thus, even other organizations under Siemens´ corporate umbrella, which conduct research in this field, may bring valuable input.

The allocation of internal and external resources was consciously rejected in the projects. It was and is part of the TRM approach, but seemed to be too time consuming and inefficient. Thus, for the sake of finishing and integrating TRM, it is postponed. However, it is important to know how technologies are realized. Information like suppliers ´names who plan radical innovations, the experts needed to develop a technology internally, or the partnerships needed to build competences for certain technologies is vital for decision making and planning of technological R&D. Synergies can be detected, and the cost of realizing the technologies to a certain point of time in the future becomes apparent and can be estimated.

It is recommended to identify the resources in the course of the next roadmapping, and not to cancel this activity as suggested by the project team. Once added, the information will barely change completely over the coming years. Certain aspects on the roadmap (i.e. product features; linkages between technologies; resources needed to realize a certain technology) are fixed. So, reviews and updates in the following years will probably not exceed two workshop days.

To conclude, the highest priority should be given to the finalization of the implementation by integrating the roadmap and the roadmapping process in the organization. Thereafter, or in parallel, business processes should be adapted/ implemented to assure closing the informational gaps by the next roadmapping run-through. Following the recommendation will enable Siemens SM to catch-up with the activities that are still undone in the current run-through and will lead to a constantly improving roadmap in the course of the next few years.

7 CONCLUSION AND DISCUSSION

7.1 CONCLUSION

All activities in the master thesis were intended to reach the two research objectives. The main objective had been to design an appropriate TRM approach for project-driven organizations. This had been achieved by deriving a theoretically appropriate approach. Afterwards, the approach had been iteratively improved by several evaluation-synthesis cycles with experts from Siemens Special Machines. An ultimate test for the TRM approach was the implementation into their organization, which can be also seen as a further iterative step in designing the TRM approach for project-driven organizations. The resulting final TRM approach consists of the TRM process, which is embedded into the implementation, and incorporates all evaluations and changes from all design steps (see appendix H). Hence, answers for sub-question one and two are given through the final TRM approach, therefore answering the main research question and consequently attaining the first research objective.

The main characteristics that differentiate the TRM approach for project-driven organizations from those in other kinds of organizations are a combination of…

…the absolute necessity to involve people/experts throughout the entire implementation to tap into the tacit knowledge embodied in the experts;

…defining precise market segments in the market workshop to deal with and display the diverse demands;

...considering production technologies in parallel to product technologies to identify their interdependencies and the linkages to product features;

…spending enough time (i.e. three workshops) in the identification and processing of technology information to deal with the complexity, and to create all the linkages between product- and production technologies and to the product features;

…identifying radical innovations to compensate for the prevailing short-term view and the imbalance between radical and incremental innovations in project-driven organizations;

…bringing in information about partner organizations, especially from own partners, to be able to process external technological developments (i.e. mostly radical innovations) where the competence lies outside the own organizations.

The second research objective has been to give Siemens SM a recommendation for their further implementation. Based on the documentation and evaluation of the implementation and the comparison to the developed TRM process, an individual and realistic recommendation could be given.

In the first step, it is recommended to finish the implementation by integrating the roadmap and the roadmapping process into the organizational systems and processes. In the second step, processes should be implemented to close the gaps which were identified in the implementation and in the post evaluation, so that finally all undone activities can be followed in the next run-through of the roadmapping process.

7.2 CONTRIBUTIONS

This thesis contributes academically in two ways. In one way, it verifies aspects about what is written in TRM literature. For instance, Phaal et al (2004a) states that TRM is a very flexible approach, which has been demonstrated by applying it in a special context and therefore adding credit on his statement. Moreover, many authors agree that it is absolutely necessary to adapt it to the specific needs of an organization (e.g. Groenveld, 1997; Garcia & Bray, 1997; Phaal et al., 2001; Lee & Park, 2005; Gerdsri, Assakul, & Vatananan, 2010), which was accomplished by taking the requirements of a project-driven organization for the development of the TRM approach. Measured by the success of the first run-through, it can be said that the T-Plan from Phaal et al (2003), including their customization approach, serves as an ideal basis to develop and customize a TRM approach for an so far untouched context. Furthermore, the success of the implementation so far confirms also the effectiveness of Gerdsri et al´s (2010) activity guideline for TRM implementation, which is based on two change management approaches and makes up major part of the here developed implementation.

The other way is that it elaborates on and adds knowledge to the existing literature. The first contribution is a theory-based definition of a project-driven organization, which had not been adequately defined in literature. The here developed definition contrasts the project-driven from non-project-driven organizations with an emphasis on the nature and effects of the production of complex products, which allows differentiating organizations by this classification.

Further, based on the literature of complex products and technology-roadmapping, a list of requirements is provided which highlights the differentiating aspects of project-driven organizations to be fulfilled when developing such a process for such type of organization.

Admittedly, the most obvious and valuable contribution is the developed TRM approach itself, adding another TRM approach to the already existing array of approaches. With help of the definition of project-driven organizations and the identified requirements of such organizations for TRM processes, the here developed TRM approach adds a differentiating approach by considering the characteristics of the special context of a project-driven business. Thereby, it builds on the literature of complex product and its effect on the organization, on the existing TRM approaches, and closes the theoretical gap identified in the thesis´ introduction.

A contribution is made for the literature of complex products, since the TRM approach offers a solution to better manage and plan complex products. A prevalent short-term view, problems in organizational learning and complexity of technologies and market requirements are typical phenomena when producing complex products. These phenomena are addressed in the TRM approach, thus offering a solution how to cope with the complexity and cope with the effects of complex products on the organization.

In a certain way, even the methodology contributes to the TRM literature, showing exactly the way how a TRM approach is developed on the basis of theory, iterative evaluation-synthesis design cycles, and practical feedback from the implementation. In contrast, many other studies are mostly retrospective case studies, focusing more on the content and the process description than on the design methodology, making it difficult for others to fully understand the methodology or copy the procedure for their study.

The practical contribution is inevitably given for all those project-driven organization who strive to implement a TRM process. Although each TRM process should be adapted to the specific situation of the subject organization, the here developed at least already considers the requirements coming from the project-driven context and fulfills the purpose of a product-technology roadmap. If the subject organization wants to have another purpose fulfilled, the roadmap´s layers probably look different, and as a consequence there is a difference in the business processes to be dealt with in the workshops. Even the time span of 10 years, as in the case of Siemens SM, may be adapted. But, for those project-driven organizations who want to implement a product-technology roadmap, the here developed and practically tested approach fits.

The practical contribution is even broader, namely for all organizations striving to implement and customize any kind of TRM approach. Since the thesis at hand outlines for its major part how to develop and implement a TRM approach, the methodology can be followed by those who want to have a TRM process implemented and cannot identify an appropriate one in the literature. The design process proved its value, which is demonstrated by the success of the project at Siemens SM, therefore serving as a reliable guideline.

7.3 LIMITATIONS

It cannot be claimed that the design process and the conducted research are free of limitations, or that the applied method represents the perfect choice to answer the research question. One of the main limitations is certainly related to the way of how the main research question is answered. In search for an appropriate TRM process, van Aken´s design problem solving circle has been applied using the empirical source of one project-driven organization. More robustness of the final TRM approach could have been reached by using a research design with multiple cases, meaning that the process is implemented in several project-driven organizations to make inter-case analyses. But, this thesis focused on one case to make a start in suggesting an appropriate process. Furthermore, it does not seem feasible to manage several implementations within the scope of one master thesis. Instead, probably only multiple retrospective case studies would seem manageable for such a thesis. In contrast, the focus on one implementation allowed not only an in depth documentation and analysis, but also personal observation as a data collection method. This enabled triangulation in the analysis of data, and increased the validity. Finally, not to forget is the similar methodological approach taken by the previous authors of TRM literature.

Certainly, another main issue is that the process had been shaped to a great extent by experts coming from one organization. It provokes the questions if the TRM approach represents the best fit to Siemens SM exclusively, or if is allowed to make inferences for other/all project-driven organizations. Undeniably, the evaluation is done only within Siemens. But thereafter, the evaluation had been backed up by further theoretical insights, so that justifications for the final design changes of the TRM approach could be made (cf. chapter 5). Thereby, it can be claimed that the final TRM process is viable and effective also for other project-driven organizations. Another, probably more precise solution would have been to establish a list of variables that allows measuring and differentiating the project-driven organization. Then, robust inferences can be made for those companies having the same profile on the variables´ scales (cf. Hobday´s measurement of CoPS in appendix A).

Another limitation is the involvement of experts in the design process. The experts for the evaluation-iteration cycle have been the same in both iterations. Moreover, the same experts have participated in the entire TRM project at Siemens. Different experts in the different iteration cycles could have brought more diverse views and feedbacks, and could have resulted in a better TRM approach. However, after the first evaluation, it had the advantage that each person exactly knew what was expected. Relationships to the expert group could be built, and the introduction of the method could be shortened in the second iteration. The experts were familiar with both, the business in project-driven organizations and the TRM process (at least after the first evaluation). Furthermore, they had personal interest, since it concerns their own organization.

A final limitation lies in the data collection for the post-evaluation. The interviews were restricted to the two project leaders, instead of interviewing each of the individuals from the project team. It may have resulted in more diverse and more robust feedback. However, the multitude of sources for the post-evaluation compensated for that.

Despite the limitations, the TRM process was evaluated by Siemens as successful. It is theoretically founded, and the major part of the process has already shown practical applicability. Therefore, further research may build on the findings of this thesis.

7.4 Future Research

Manifold studies exist about technology-roadmapping. It has been applied in many contexts, and this thesis incorporates another TRM approach for a new context. The question is now in how far this thesis can elicit or enable further research.

For one, it can provoke researchers to further customize TRM for other specific situations, maybe even unrelated to the context of project-driven organizations. This thesis demonstrates that requirements differ per context, thus motivating others to continue research on identifying requirement of different contexts and connecting them to TRM approaches.

Another direction is to build on this thesis and differentiate between different characteristics of project-driven organizations. The definition in this thesis generalizes all project-driven organizations; however, differentiation may lead to diverging requirements for a TRM approach. For example, what if you differentiate in the degree of product complexity (high very till very low)? Do the requirements change between organizations producing very complex and complex products? Product complexity can be measured using a multitude of variables (Mike Hobday, 1998). What if complexity is in average high although not all variables indicate complexity? Are the requirements and therefore the TRM process still the same? More examples would be to differentiate on basis of size of the project-driven organization (large-medium-small) or between complex products versus complex services.

Future research can also focus on the application of the here developed approach in further project-driven organizations. This would verify the here developed approach and leads to a certain robustness. Moreover, studies may focus on the combination of the here developed approach with other methods from technology management (i.e. foresight) to develop integrated approaches for project-driven organizations. Or in contrast, other researchers might have a different idea on how a TRM process has to look like, therewith challenging the here developed design.

To conclude, this thesis serves as a solid basis on which further research can be built, the same as it can provoke researchers to go more into detail (e.g. differentiating project-driven organizations) or challenge the results by taking, for instance, a different theoretical basis.

7.5 Reflection

Although the previous sections of this chapter already forced to reflect about certain aspects of the thesis, a personal reflection completes the impression the reader should take away.

In my opinion, the Siemens project was a unique opportunity to embed and conduct a master thesis, which allowed designing and evolving a TRM approach through iterative steps involving many different experts. The results are very satisfying, although the design process was very messy in between.

Despite the messiness, the methodology and the related research were conducted thoroughly, representing the reality as close as possible. Especially the different data collection methods for the evaluation – in particular the ongoing personal involvement in the project – contribute to this point, allowing triangulation of data.

Of course, the research had its limitations, but every research design has its weaknesses. Given the situation and the resources, I would do the thesis exactly the same if I have to do it again.

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APPENDIX A – MEASUREMENT OF COPS

Complex products and system (CoPS) – To what degree is your organization producing CoPS?

Product dimension and measurement of complexity	Measurement of the dimensions				
	Very high	High	Average	Low	Very low
Unit cost/ financial scale of project					
Product volume (inverse of)					
Degree of technological novelty					
Extent of embedded software in product					
Quantity of subsystems and components					
Degree of customisation of components					
Complexity and choice of system architectures					
Quantity of alternative component design paths					
Feedback loops from later to earlier stages					
Variety of distinct knowledge bases					
Variety of skill and engineering inputs					
Intensity of user involvement					
Uncertainty/ change in user requirements					
Intensity of other supplier involvement					
Intensity of regulatory involvement					

Table 2: Measurement of product dimensions and complexity [14]

[14] Source: (Mike Hobday, 1998)

APPENDIX B – DEVELOPMENT OF THE TRM APPROACH

Step 1: Development of the theory-based TRM approach

The theoretical foundation consists of:

- T-Plan (section 2.1.2)
- Customization literature (from the T-Plan) (section 2.1.3)
- Implementation literature (section 2.1.4)
- Requirements of project-driven organizations (section 2.2 & 2.3)

The standard process of the T-Plan serves as the skeleton for the development of the TRM approach for project-driven organizations. Since the TRM process depends on the roadmap to be developed, the roadmap has to be defined first. The roadmap, in turn, is dependent on the purpose.

The purpose to be fulfilled is in this case *"to link business and technology to ensure market-driven innovation capabilities to meet future business goals"*[15]. According to the classification from Phaal et al (section 2.1.1), such purpose is fulfilled with a product-technology roadmap (section 2.1.1), one of the most common roadmaps developed by organizations and in line with the intention of the master thesis.

The basis for the product-technology roadmap is given by EIRMA (section 2.1.1). Since in project-driven organizations the product and production are highly interdependent (section 2.2), the roadmap needs an additional layer, production. The time-span for the future perspective was set to 20 years to enclose the long technology life-cycles present in project-driven organizations (section 2.2). (See figure 11 for the resulting roadmap)

Based on that roadmap, the T-Plan can be adapted. Phaal et al urge to customize the process where necessary. For the application in project-driven organizations, the respective theory is taken to customize the T-Plan accordingly. Therefore, in section 2.3, the requirements for project-driven organizations with respect to TRM are formulated, which are:

- The market layer should display certain external drivers, namely regulation, norms, and political influences

[15] Source: Internal document from the planning phase of the TRM project at Siemens Special Machines

- Production (planning) should be explicitly considered. Therefore, the future development and options are to be discussed and linked to product technologies and features.
- The development of a long-term view is important, which means for the future perspective to identify and fill gaps in the separate layers of the roadmap. Moreover, the far future should be discussed (for example 15-20 years) instead of only the following five years. Additionally, technology benchmarking to other industries elicits interesting future perspectives for own products.

The resulting theory-based technology roadmap and TRM approach are as follows:

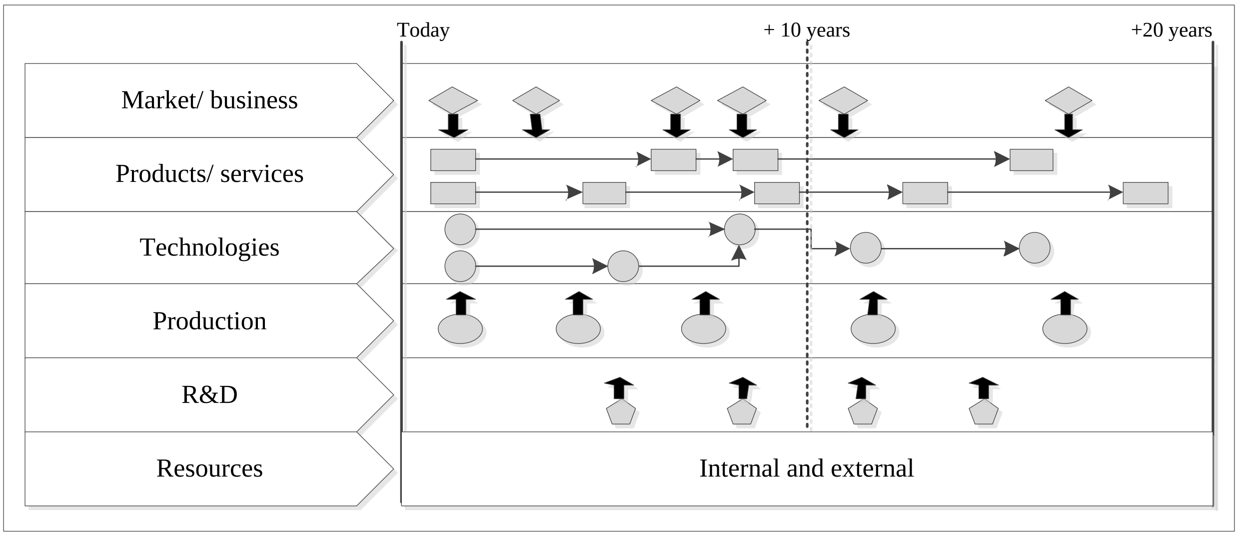

Figure 11: First version of the product-technology roadmap for project-driven organizations

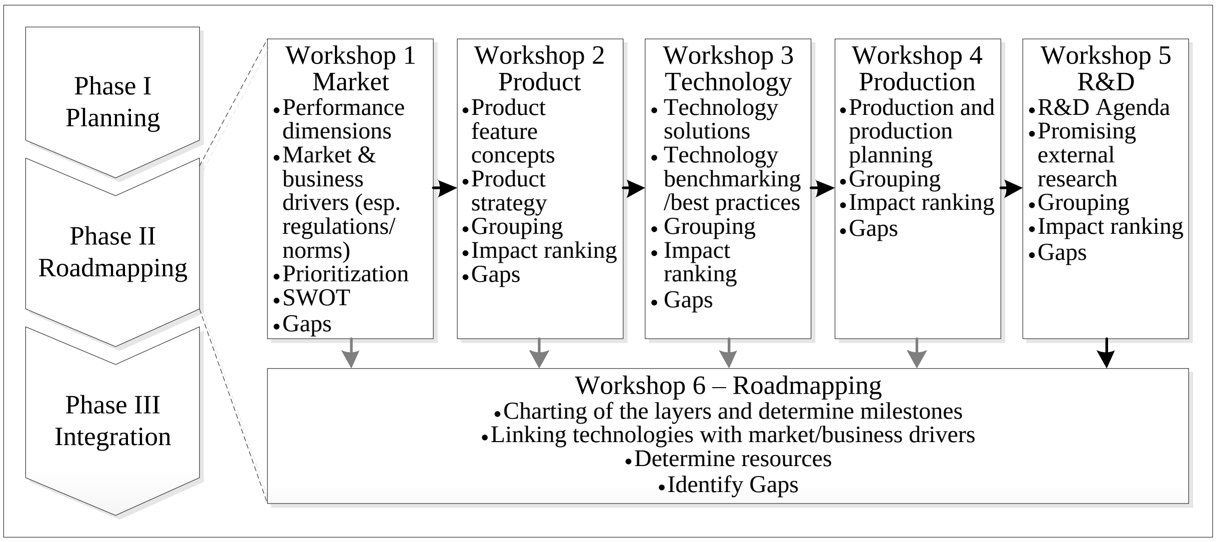

Figure 12: Theory-based TRM approach

For each of the six layers, a workshop is planned. As in the T-Plan, each workshop serves as a major milestone in which the necessary information for the respective layer is collected, discussed and linked to the other layers. The actual charting is included in the final workshop, next to the resource identification.

Due to the weaknesses of the T-Plan (section 2.1.4) with respect to phase I, initiation, and phase III (integration), Gerdsri et al´s approach (section 2.1.4) is used to complement the T-Plan in order to define the two phases according to the needs of project-driven organizations. (See section 3.2 for the elaboration of the two phases)

Step 2: First expert evaluation and adaption of the TRM approach

In the first group meeting, the proposal for the TRM approach is presented. In this meeting, most of the project team members are confronted with TRM for the first time. So, this session is also a training session, where all members get an introduction to TRM. After the introduction and the explanation of the intentions, the TRM approach has is discussed and evaluated.

In general, the project team agrees on the approach. Phase I and III are accepted without any critique. With respect to the roadmapping process, the group agrees on the following aspects:

- The time span of 20 years is too long for a project-driven organization. The prevailing short-term view and the uncertainties make it even difficult to look one decade ahead. The time span should be rather set to 10 years.
- Once the entire group of experts is present, it was seen as an opportunity to conduct a SWOT analysis instead of only a gap analysis for the respective business area in workshop 1 (marketing), workshop 4 (production) and workshop 5 (R&D/ Engineering).
- The workshops need a preparation phase. With respect to the complexity of information/knowledge existent in project-driven business, this seems necessary to be able to handle the complexity of information needed and to prepare it adequately for the workshop session. The team agreed having a catalogue of important questions to be answered in the workshop sent to each team member prior to the workshop. Then, everybody can add questions and send it back to the project leader. The complete question catalogue is finally sent to the “expert of the day”, so that he/she prepares the responses in order to deliver an adequate information basis for the workshop.
- As a chance to verify the results of a workshop and/or to add further information to the results, a post-evaluation meeting with the “expert of the day” is wanted. Between the workshop and the post-meeting, the expert´s department may find further important aspects that fill gaps or give new insights.

Step 3: Second expert evaluation and adaption of the TRM approach

In the kick-off meeting directly before the workshop-series, the TRM approach is reviewed the second time by the project team. This time, all members are already familiar with TRM. The discussion is rather short and everybody agrees on the approach. If problems occur, the team would intervene during the implementation. (See section 3.2 for the TRM approach before implementation)

APPENDIX C – PERSONAL OBSERVATION (DOCUMENTATION)

During the workshops, hand-written notes were made with respect to strong and weak aspects of the originally planned TRM approach. After the respective workshops, the notes have been transferred into the following tables to display the strengths and weaknesses, the solutions for the obstacles, and the references to Siemens´ project documents. (cf. section 4.1)

Workshop 1 - Market

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
	Identification of performance dimensions not feasible, since markets are too heterogenic and performance dimensions vary with them	Differentiation per market segment; definition of homogeneous market segments	Excel-table with segmentation and rating
15 performance dimensions could be identified and rated for the separate market segments			Excel-table with segmentation and rating
Market and business drivers could be derived from performance dimensions and prioritized			Picture from workshop 1
SWOT analysis revealed interesting and valuable weaknesses			Workshop´s documentation

Table 3: Workshop 1 documentation (strengths and weaknesses of TRM approach)

Workshop 2 – Product features

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
Product features were derived from performance dimensions, with the help of a specification list (typically used by customers for orders)			Picture from workshop 2 (flipchart)
Brainstorming led to more product features (with help of product strategy)			Picture from workshop 2 (flipchart)

Non-relevant product features were removed from the list (with help of product strategy); the rest was condensed and grouped			Picture from workshop 2 (flipchart)
As a result, 17 product features were identified			Excel-table with rating (drivers-product features)
Product features were confronted with drivers and rated in impact			Excel-table with rating (drivers-product features)

Table 4: Workshop 2 documentation (strengths and weaknesses of TRM approach)

Workshop 3 – Technology

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
	The complexity of the technology information (> 250 technologies!) was too high to handle in one workshop completely	The technology workshop led to an overview of all technologies; in the following workshops, the product- and production technologies should be elaborated respectively.	Presentation of workshop 3
More than 250 technologies (from product and production) were allocated to 25 technology groups			Extensive technology list in excel file and the workshop´s presentation
	Best practices and benchmarking was not done very thoroughly and led to practically no additional technologies	No solution, since it was a time issue that this activity was neglected	
Technology groups were rated in impact for the product features from workshop 2			Excel-table with rating (technologies-product features)

Table 5: Workshop 3 documentation (strengths and weaknesses of TRM approach)

Workshop 4 – Production

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
	The original agenda did not fit any more to the new logic which was implemented in	The content of the workshop had to be adapted. The new milestones of this	Workshop´s documentation and excel technology profiles

	workshop three	workshop were to elaborate on the production technologies (identification, development over time, link to other technologies and to product features)	
15 production technologies were discussed in detail (their development and their link to other technologies) via technology profiles			Technology profiles from workshop 4 and workshop´s presentation
Technologies/developments were prioritized and top technologies/developments were identified			Excel table with rating (production technologies-product features)
In the end, a SWOT analysis for the production technologies revealed many valuable opportunities			Workshop´s documentation

Table 6: Workshop 4 documentation (strengths and weaknesses of TRM approach)

Workshop 5 – Product technologies/ R&D

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
	The original agenda did not completely fit to the new logic which was implemented in workshop three	The change was to elaborate on the product technologies from workshop 3. The rest remained the same.	Workshop´s documentation and technology profiles
24 product technologies were discussed using the same template (technology profile) as in workshop four; the development over time (with help of the R&D agenda) and the linkages to other technologies (brainstorming) were identified			Technology profiles from workshop 5 and workshop´s presentation
Technologies/developments were prioritized and top technologies/developments were identified			Excel table with rating (product technologies-product features
	Major focus was on internal developments. External one were coming too short, were practically neglected. It		Workshop´s documentation and technology profiles

	was said: “On whom do you want to look when you are technology leader?”		
A SWOT analysis revealed many knowledge gaps.			Workshop´s documentation

Table 7: Workshop 5 documentation (strengths and weaknesses of TRM approach)

Workshop 6 – Product technologies/ R&D

Strengths	**Weaknesses**	**Solution**	**Further Reference** (not enclosed, since it is too confidential)
Major milestones for each market segment´s drivers were charted in the market layer of the roadmap			Final roadmap
Product feature milestones were charted, and linked to the market milestones			
	Focus on major technology milestones would give an incomplete and wrong picture; too many interdependencies could not be displayed; roadmap could not be quickly adapted to changing priorities	To stay flexible, all technologies and their development were charted; only the main linkages to the upper layers are based on the current priorities	Final roadmap
	Resources were not identified, since it would have been very time consuming to do so for all technologies; it was said:”There is no time left in this workshop to plan the resources for each technology.” And “It would be too time consuming, considering that it is done during the workshop with all the experts.”	No solution, since it was a time issue that this activity was neglected	
Gap analysis was conducted but has not revealed additional gaps			Workshop´s documentation

Table 8: Workshop 6 documentation (strengths and weaknesses of TRM approach)

Appendix D – Post-Evaluation (Project Team)

To receive an overall evaluation from the entire project team, a feedback round was conducted in the end of workshop six. Most of the feedback has been collected on a flip chart. However, some aspects were mentioned in between. In general, the feedback circled around some major points, which are presented in the following table:

Strengths	**Weaknesses**
(1) Das Ergebnis ist gut und repräsentiert den aktuellen Kenntnisstand	(3) Berücksichtigung von extern-gesourcten Technologien muss beachtet werden
(2) Die Perspektiven wurden abgeglichen	(4) Stärkerer Blick über den Tellerrand
	(5) Radikale Innovationen sollten mehr betrachtet werden

Table 9: Project team´s evaluation of the implementation/process

Translation/Interpretation

The project team is satisfied with the result (1). The roadmap is developed and represents the current state of knowledge (1), which means that the TRM process works. Perspectives between the departments were aligned (2).

However, there are still some weaknesses in the process. It was criticized that the external view (i.e. external technologies) has to be considered (3). Furthermore, radical ideas must be processed, too ((4) & (5)).

APPENDIX E – POST-EVALUATION (INTERVIEW GUIDELINE)

Interview	Post-evaluation of the implementation
Interview type:	Face-to-face
Language:	German
Location:	Siemens Special Machines, Germany

1. Was the TRM process and its implementation successful? (War die Einführung und der TRM Prozess erfolgreich?)

- In how far successful
- In how far not successful
  - Compared to the initial goals
  - Goals with respect to the roadmap
  - Goals with respect to the process
  - Goals with respect to the implementation
  - Fulfillment of requirements for project-driven organizations/CoPS producer

2. Where were difficulties in the TRM process and implementation? (Wo waren die Probleme/Schwierigkeiten im TRM Prozess und bei der Einführung?)

- Are they related to project-driven/CoPS character?
- With respect to the initiation
- With respect to the process (i.e. preparation, workshops, post-meetings)
- Integration

3. Would you say that the process fits to the organization? (Würden Sie sagen, dass der Prozess so zur Organisation passt?)

- In how far does it (not) fit
- (Why does it not fit)

APPENDIX F – POST-EVALUATION (INTERVIEW FROM 2012-06-04)

INTERVIEW TRANSCRIPT

Interviewee:	Mr. Dr. H. K.
	Siemens Special Machines (I DT LD AP SM)
	Head of R&D (EN)
Interview type:	Face-to-face
Language:	German
Date:	2012-06-04
Initials:	K. (Interviewee) → K
	Lanfer (Interviewer) → L

L: War die Einführung und der Prozess in Ihren Augen erfolgreich? Inwiefern wurden die Ziele erreicht?

K: Meiner Vorstellung nach sind sie erreicht worden. Wir haben erreicht, dass wir uns alle mal zusammengesetzt und die Meinung abgeglichen haben. Das hat mehr Wert als man normalerweise denkt. Jeder denkt ja normalerweise nur in seiner Funktionalität. Wir haben die wichtigsten Entwicklungspunkte diskutiert. Wir haben zudem jedem erst mal klar gemacht wofür die überhaupt gut sind. Das ist schon mal ein großer Schritt, dass jetzt alle auf dem gleichen Wissensniveau mitdenken können. Und dann haben wir ein Beispiel in Form der ersten Roadmap auch schon erarbeitet. Damit haben wir für Entscheidungen eine erste Basis gebildet. Jetzt muss der Prozess nur noch mit Routine gefüllt werden. Und da muss jetzt jemand eine Entscheidung treffen wie wir dort weiter machen.

L: Es gibt also keine Ziele die nicht erreicht wurden?

K: Es gibt ein paar Themen, die noch nicht behandelt wurden, wie zum Beispiel das Thema Personalentwicklung, Kapazitäten, Ressourcen. Diese Aspekte wurden noch nicht sauber beleuchtet. Auch noch nicht beleuchtet wurde das Zusammenspiel der Funktionen im Konzern. Das darf man nicht außer Acht lassen. Wir haben bestimmte Funktionalitäten, die nicht in Special Machines liegen. Zum Beispiel wurde der Abgleich zur zentralen Entwicklung noch nicht gemacht. Also, der Prozess ist noch nicht fertig, sondern wir haben eine Basis auf die man aufsetzen kann.

L: Wo gab es Probleme/Schwierigkeiten im kompletten Prozess und in der Einführung?

K: Die Hauptschwierigkeit ist Kapazitäten dafür auszulösen, und dass überhaupt Leute Zeit haben um sich damit zu beschäftigen. Das ging durch die strukturierte Herangehensweise mit den Workshops und der Vor- und Nacharbeit im engeren Team gut über die Bühne. Und es ist auch anerkannt worden. Schwierigkeiten wird es erst geben wenn so ein Prozess Geld kostet und Personal erfordert. Wenn es jetzt darum geht langfristige und teure Maßnahmen von der Roadmap umzusetzen, dann wird nach Kassenlage entschieden. Deswegen muss noch die Wunschvorstellung der Roadmap noch mit der Realität in Einklang gebracht werden. Desweiteren muss noch die Kontinuität in solchen Projekten erreicht werden. Dies ist besonders relevant in projektgetriebenen Geschäften, da die Verschiebung in Prioritäten in kurzen Abständen und die damit verbundene Kapazitätsverschiebung zum Halt von solchen Langzeitprojekten führen kann. In Serienprodukten sind Prioritätsverschiebungen seltener der Fall und erlaubt somit auch Langzeitprojekte mit größerer Sicherheit zu verfolgen. Die Prioritätsverschiebungen sind spontan, aber auch berechtigt spontan im Spezialmaschinengeschäft.

L: **Würden Sie sagen, dass der Technologie-Roadmapping Prozess, wie Sie ihn entwickelt haben, so zur Organisation und zu Siemens SM passt?**

K: In der jetzigen Organisation war der Weg richtig. Die Frage ist ob die Organisation für alle Ewigkeit so vorgeschrieben ist. Zum einen gibt es eine geschäftsorientierte Organisation, welche wir auch schon hatten und die nach Geschäftsfeldern strukturiert war. Zum anderen gibt es eine funktionale Struktur, wie wir es im Augenblick haben. Es hat beides Vor- und Nachteile. In der aktuellen funktionalen Organisation passt das mit dem Prozess. Im Prinzip ist diese Roadmap ja fachlich bezogen, und dann muss sie nur bei der Umsetzung entsprechend an die aktuelle Organisation angepasst werden.

ANALYSIS

Text excerpt	**(Interpretative) Translation**	**Interpretation/ Classification** (Strength or weakness)
Meiner Vorstellung nach sind sie erreicht worden.	All goals were reached	Strength: TRM approach is effective with respect to the set goals
[…]dass wir uns alle mal zusammengesetzt und die Meinung abgeglichen haben.	Goal: Opinions/ Perspectives were aligned	Strength
[…]die wichtigsten Entwicklungspunkte diskutiert. […]zudem jedem erst mal klar gemacht wofür die überhaupt gut sind.	Goal: The most important points for development were discussed, and everybody now known for what they are good for	Strength
[…]alle auf dem gleichen Wissensniveau mitdenken können.	Goal: All team members are now on the same knowledge/ information level	Strength
[…]ein Beispiel in Form der ersten Roadmap auch schon erarbeitet und […] für Entscheidungen eine erste Basis gebildet.	Goal: First roadmap was developed and can be used as a decision basis	Strength
[…] Personalentwicklung, Kapazitäten, Ressourcen […] wurden noch nicht sauber beleuchtet.	Some aspects were not soundly dealt with so far, which are personnel, capacities, and other resources	"Weakness" Note: It was planned for workshop 6, but due skipped due to time problems
Auch noch nicht beleuchtet wurde das Zusammenspiel der Funktionen im Konzern. Zum Beispiel wurde der Abgleich zur zentralen Entwicklung noch nicht gemacht.	Functional relations to the corporation were not considered. For example, there was no alignment to the central R&D department	"Weakness" Note: Actually, the own R&D department was supposed to enter this information, as their R&D agenda should be aligned to the central R&D department
[…] durch die strukturierte Herangehensweise mit den Workshops und der Vor- und Nacharbeit im engeren Team gut über die Bühne. Und es ist auch anerkannt worden.	Due to the structural approach (workshops; workshop agenda; preparation and post-evaluation), the entire process was accepted and went smoothly	Strength: The TRM approach removed/avoided barriers of change
In der jetzigen Organisation war der Weg richtig.	In the current organization, it was the right way	Strengths: It fits to the situation, which means that the approach is valid

Table 10: Transcript analysis (Interview from June 4th 2012)

APPENDIX G – POST-EVALUATION (INTERVIEW FROM 2012-06-07)

INTERVIEW TRANSCRIPT

Interviewee:	Mr. F. S.
	Siemens Special Machines (I DT LD AP SM)
	Engineer (EN)
Interview type:	Face-to-face
Language:	German
Date:	2012-06-07
Initials:	S. (Interviewee) → S
	Lanfer (Interviewer) → L

L: Jetzt ist das Projekt zur Erstellung des TRM Prozesses und die Einführung samt Erstellung einer ersten Roadmap beendet. Inwiefern wurden die Ziele erreicht? Würden Sie sagen, dass die Einführung und der Prozess erfolgreich waren?

S: Ein klares „ja". Wir haben zu einen den Prozess erstellt, der sich für praktikabel erwiesen hat. Über die verschiedenen Workshops und über die Einbeziehung relativ vieler Experten sind wir dann doch zu einem relativ konzentrierten Ergebnis gekommen. Zum anderen haben wir viele niedergeschriebene Informationen, die man gut als Rücklage für einen zweiten Durchgang nehmen kann. Sicherlich ist die erste Roadmap noch nicht der Weisheit letzter Schluss. Aber das Grundgerüst ist nach meiner Sicht schon hervorragend, an dem ich jetzt noch ein wenig drücken und schieben muss, um die Inhalte in die richtige Reihenfolge zu kriegen und noch die eine oder andere Information zu ergänzen. Uns sind im Prozess die Lücken bewusst geworden die es jetzt heißt zu schließen.

L: Gibt es irgendwelche Ziele oder Erwartungen, die nicht erreicht wurden?

S: Nein, nicht von den eigentlich ursprünglichen Erwartungen. Diese wurden erfüllt. Es gab zwischendurch mal Seitenbefindlichkeiten, wie zum Beispiel eine gewollte Kapazitätsplanung. Aber das konnte und sollte die Roadmap und der Prozess gar nicht befriedigen.

L: Gab es denn irgendwo Probleme oder Schwierigkeiten in der Einführung und vor allem in dem Prozess?

S: So wie wir es durchgeführt haben war es rückblickend betrachtend sehr gut. Sehr schwierig wäre es gewesen diesen Prozess ohne eine externe Betreuung durchzuführen. Das wäre – meine ich – gescheitert, da wir uns an vielen Stellen verzettelt hätten. Da wären Diskussionsclubs zwischen den Experten entstanden, hätten wir nicht den neutralen Mediator gehabt, der die Methodik des Roadmapping beherrschte. Und das bezieht sich nicht nur auf das Roadmapping, sondern fängt schon mit dem Brainstorming in der Gruppe an. Eine „Methodenpolizei“ ist bei dem gesamten Prozess extrem wichtig. Vor allem bei einem projektgetriebenen Geschäft wie es Siemens SM ist, einfach aufgrund der Vielzahl der Experten die involviert sind.

L: Würden Sie sagen, dass der Technologie-Roadmapping Prozess, wie Sie ihn entwickelt haben, so zur Organisation und zu Siemens SM passt?

S: Er hat funktioniert! Er hat funktioniert, denn wir haben Defizite erkannt und er kann vermutlich an manchen Stellen modifiziert werden. Aber vom Grundansatz würde ich sagen, er passt zu uns.

L: An welchen Stellen würden Sie modifizieren?

S: Ich denke, bei dem Part über die Markttreiber und Produkteigenschaften müssten wir uns mehr Zeit nehmen und Mühe geben, um die fehlenden Informationen zu generieren und zusammen zu sammeln. Der Rest steht mehr oder weniger fest, wie zum Beispiel die Technologiewechselwirkungen. Auf der Technologieebene kennen wir uns gut aus, aber der Vorbau von Markt- und Produktinformationen muss noch genauer erarbeitet werden.

ANALYSIS

Text excerpt	(Interpretative) Translation	Interpretation/ Classification (Strength or weakness)
Ein klares „ja“.	Yes, the TRM approach has been successful	Strength: TRM approach is effective for the developed purpose
Wir haben zu einen den Prozess erstellt, der sich für praktikabel erwiesen hat.	TRM approach was developed/customized and proven in practicability	Strength: TRM approach is practicable and allowed for improvements on the way
Über die verschiedenen Workshops und über die Einbeziehung relativ vieler Experten zu einem relativ konzentrierten Ergebnis gekommen.	The procedure (workshops; involvement of experts) led to a relatively concentrated result.	Strength: TRM procedure is beneficial and leads to a good result.
[…] niedergeschriebene Informationen, die man gut als Rücklage für einen zweiten Durchgang nehmen kann.	For the next run-through, much information has been already collected (i.e. gaps to fill, etc.)	Strength: The approach produces valuable input and feedback, that is relevant for the next run-through
Sicherlich ist die erste Roadmap noch nicht der Weisheit letzter Schluss. Aber das Grundgerüst ist nach meiner Sicht schon hervorragend, an dem ich jetzt noch ein wenig drücken und schieben muss […]	The first roadmap is not perfect. In principle, it fits, but it has to be complemented and improved in a review	Strength: First roadmap is a good basis. Weakness: The roadmap is not complete yet.
Uns sind im Prozess die Lücken bewusst geworden die es jetzt heißt zu schließen.	The gaps were identified and must be closed now.	Strength: TRM approach is effective in the identification of gaps
Nein, nicht von den eigentlich ursprünglichen Erwartungen. Diese wurden erfüllt.	Not from the actual expectations. These have been fulfilled.	Strength: TRM approach is effective for the developed purpose
So wie wir es durchgeführt haben war es rückblickend betrachtend sehr gut.	In retrospective, the process we followed was good.	Strength: TRM process was effective/practicable
Sehr schwierig wäre es gewesen diesen Prozess ohne eine externe Betreuung durchzuführen. Das wäre – meine ich – gescheitert, da wir uns an vielen Stellen verzettelt hätten. Da wären Diskussionsclubs zwischen den Experten entstanden, hätten wir nicht den neutralen Mediator gehabt, der die Methodik des Roadmapping beherrschte. Vor allem bei einem projektgetriebenen Geschäft wie es Siemens SM ist, einfach aufgrund der Vielzahl der Experten die involviert	It would have been difficult to follow the process without an external consultant, who was valuable as mediator and expert in TRM and workshop methodology	Strength: The involvement of an external consultant as mediator and methodological expert is a strength

sind.		
Er hat funktioniert […]. […] vom Grundansatz würde ich sagen, er passt zu uns.	The TRM process fit to Siemens SM	Strength: The TRM process fits to the organization/situation, which means that the approach is valid
[…] bei dem Part über die Markttreiber und Produkteigenschaften müssten wir uns mehr Zeit nehmen und Mühe geben, um die fehlenden Informationen zu generieren und zusammen zu sammeln.	We have to invest more efforts into the market drivers and product features to generate/collect the necessary data to close the gaps	Strength: Gaps in the organization were identified

Table 11: Transcript analysis (Interview from June 7th 2012)

APPENDIX H – FINAL TRM APPROACH

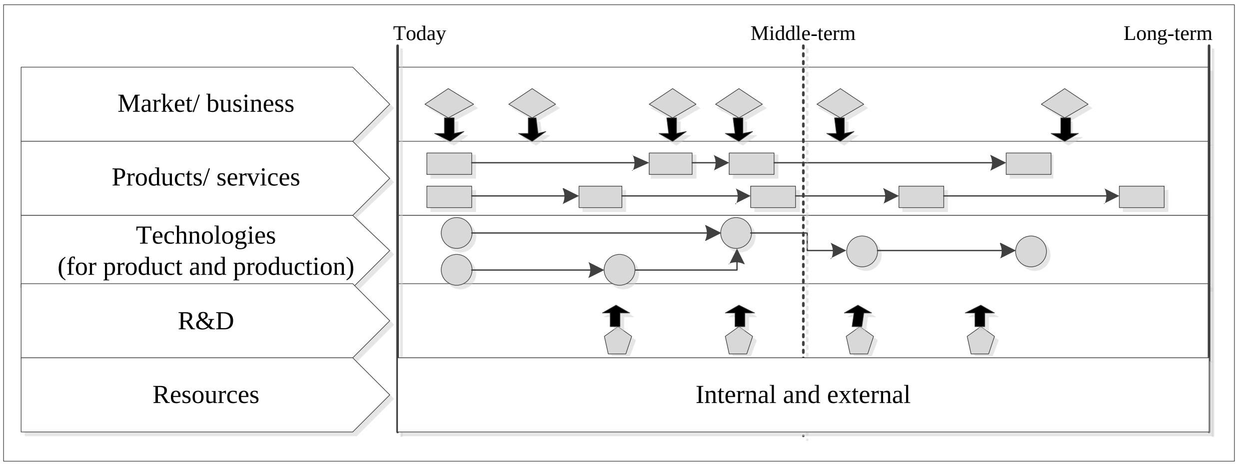

Figure 13: Final product-technology roadmap for project-driven organizations

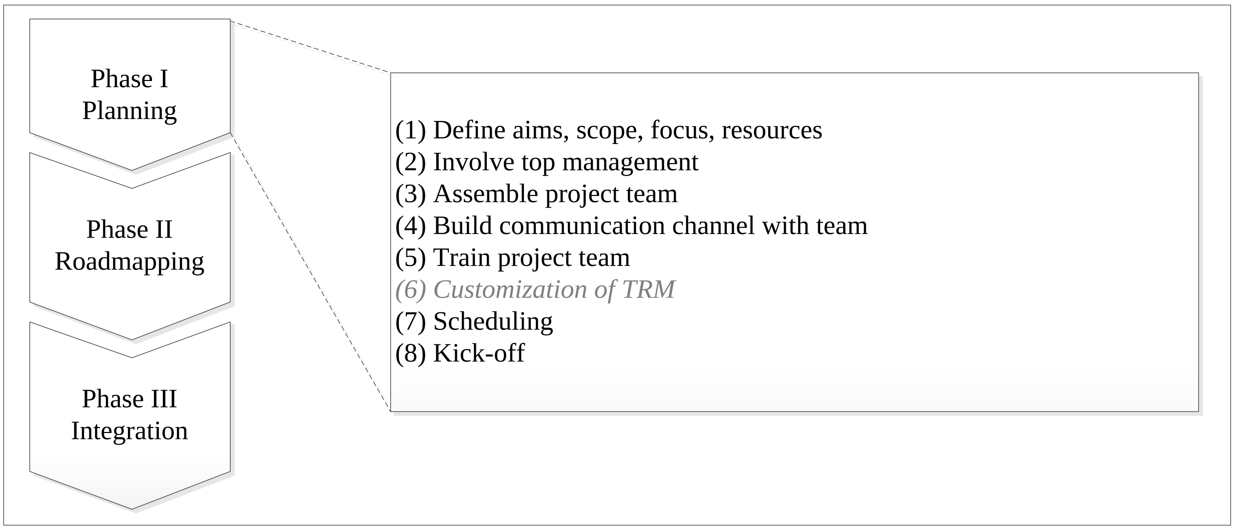

Figure 14: Final TRM approach – phase I (initiation)

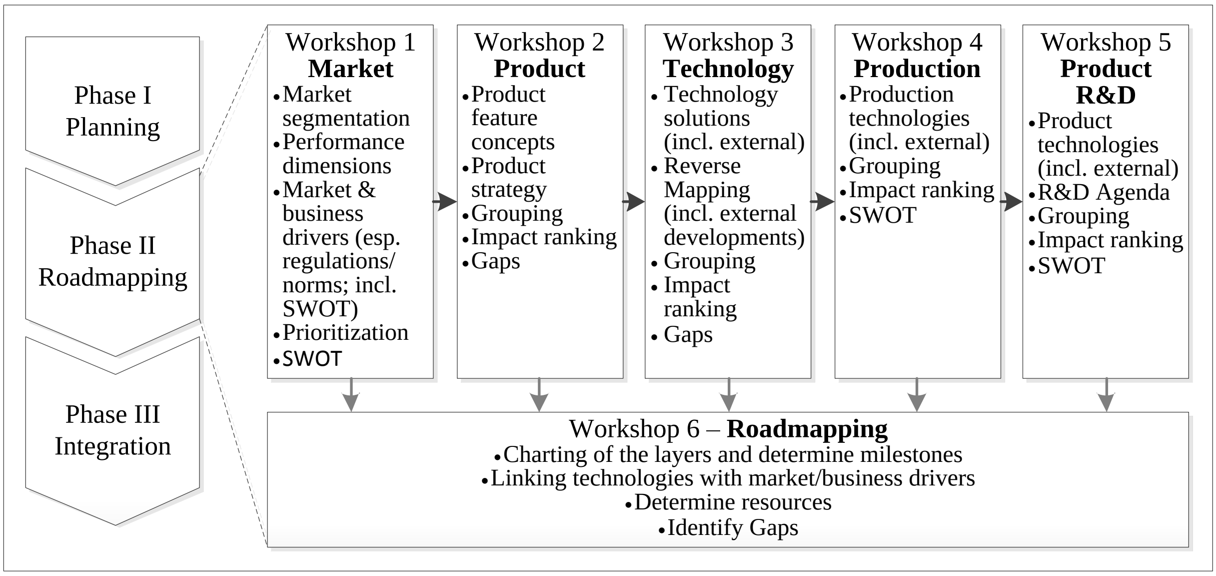

Figure 15: Final TRM approach – phase II (TRM process)

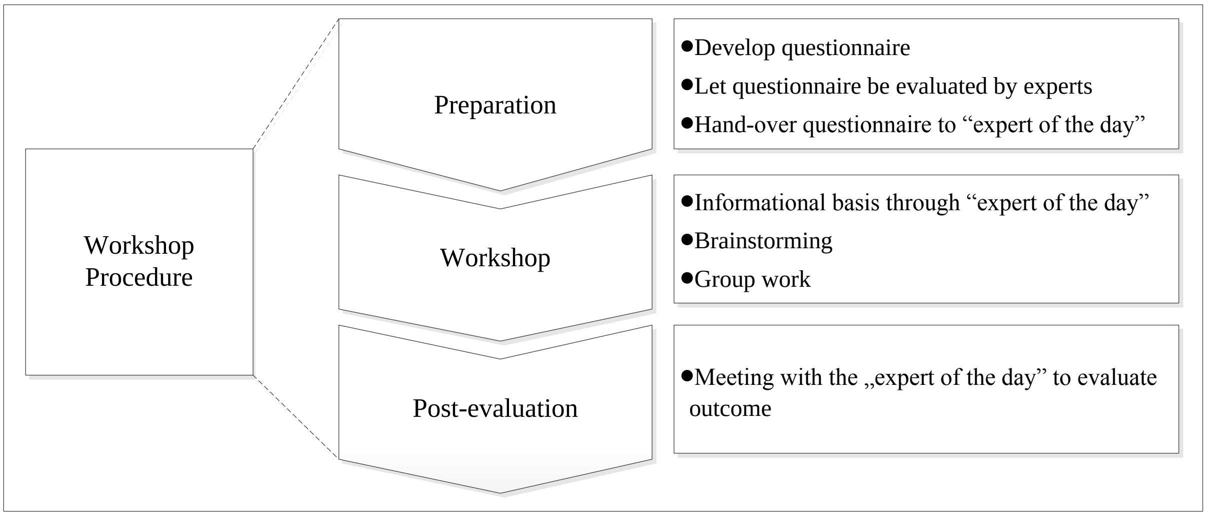

Figure 16: Final TRM approach – workshop procedure

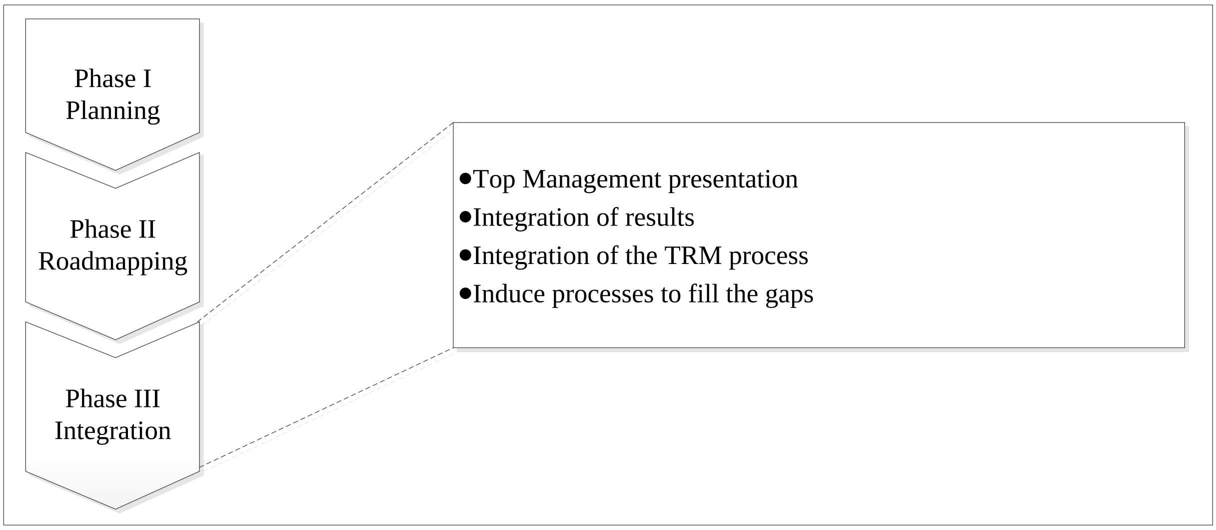

Figure 17: Final TRM approach – phase III (integration)