Technology roadmapping to develop the innovation strategy in engineering consultancy

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Summary

Engineering consultancy firms have to deal with digital innovations. To keep up with the competition, they have to balance the exploration and exploitation of innovations. Planning brings a structured approach to the execution of the two activities, balancing them. The method of technology roadmapping (TRM) can be used to plan the exploration and exploitation of innovations.

TRM supports its users with the integration of technology into a strategic business context through strategic and long-range planning. TRM has been used in service-oriented industries, however, this TRM method is not applicable in engineering consultancy to develop an innovation strategy. Therefore, a new TRM method had to be designed for engineering consultancy firms to develop their innovation strategy.

The designed TRM method consists out of preparing the workshops and a workshop phase. In the preparing the workshops phase, the workshops are customised to the organisation. In the workshop phase through four workshops, data about the why, what, how, and when of organisation's innovation strategy are processed by a team with expert knowledge of the industry.

The method was designed in two consecutive but different design cycles. In the first design cycle, seven requirements were introduced based on the stakeholders' goals. The TRM method was designed by comparing six TRM methods from literature along six criteria that would aid with designing a TRM method compliant with the requirements. The new TRM method used elements from the T-plan workshop structure by the Cambridge practical school and implementation-oriented roadmapping by the Portland/Bangkok school. One requirement could not be verified during verification as the designed TRM method lacked operation details; this called for a second design cycle.

In the second design cycle, the designed TRM method was enriched with operational details based on literature resulting in an hourly workshop planning and detailed description of the tools used during the workshops. With the additional details, validation was possible. The validation and implementation happened in a specialist group at Sweco. First, the implementation was evaluated in an interview with three workshop participants and was considered successful. The validation was successful as all requirements were met during the implementation of the TRM method. As a result, the research goal to design a TRM method that allows engineering consultancy firms to develop their innovation strategy was achieved along with a real-world validation of the designed TRM method.

Keywords: Innovation strategy, technology roadmapping, T-plan, case study, design science, technical action research, engineering consultancy

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1 Introduction

Firms continuously try to improve their position in the market by exploiting their current knowledge and exploring new knowledge, technologies and methods (Eriksson, 2013). Service-oriented firms such as engineering consultancy – which do not trade physical goods, but offer knowledge and experience of a specific engineering speciality e.g. railway maintenance or transmission pipelines – require strategic planning to maintain their position in the market. Service oriented firms can, for example, implement new technologies to support their engineering processes, or deliver digital models for the engineering industry.

Project-based organisations (PBO) in the construction industry – such as engineering consultancy firms – experience difficulty integrating these innovations through the organisation (Eriksson, 2013). Due to this difficulty integrating the explorative innovations, they are not diffused through the organisation and therefore innovations are not exploited by the entire organisation (Hobday, 2000).

Explorative innovation processes require money and time, which might compete with short-term goals of exploiting capability and making profit. Finding a balance between the short and long term goals is complex. It requires ambidexterity, the capability to exploit the existing knowledge and technologies for the short-term and explore new knowledge and technologies to enhance long-term development (O'Reilly & Tushman, 2008).

To find the balance between the exploration and exploitation of innovations, it is helpful to plan these activities. Planning exploration and exploitation means determining the aim, time, and money spend on these activities up front. They can then be executed in a structurally manner rather than leaving the balance to chance.

The method technology roadmapping (TRM) can be used to plan the exploration and exploitation of innovations. TRM originated as a strategic planning method for product-oriented firms such as BP, Philips, General Motors, Siemens, and Lego (Barker & Smith, 1995; Groenveld, 1997; Grossman, 2004; Kerr et al., 2019; Lischka & Gemunden, 2008). TRM supports its users with the integration of technology into a strategic business context. The method requires the users of the TRM method to first specify the organisational goals or targets, see the 'market' layer of Figure 1. Next, the users specify the products they want to sell to the customers, i.e. the exploitation, see 'product' layer. The 'technology' layer contains the exploration of innovation in Figure 1. By placing the exploration and exploitation activities in the same figure on a timeline, the *technology roadmap* as seen in Figure 1, a balance between exploration and exploitation is created and can be maintained. More detail about TRM can be found in chapter 2.1 Introduction to technology roadmapping.

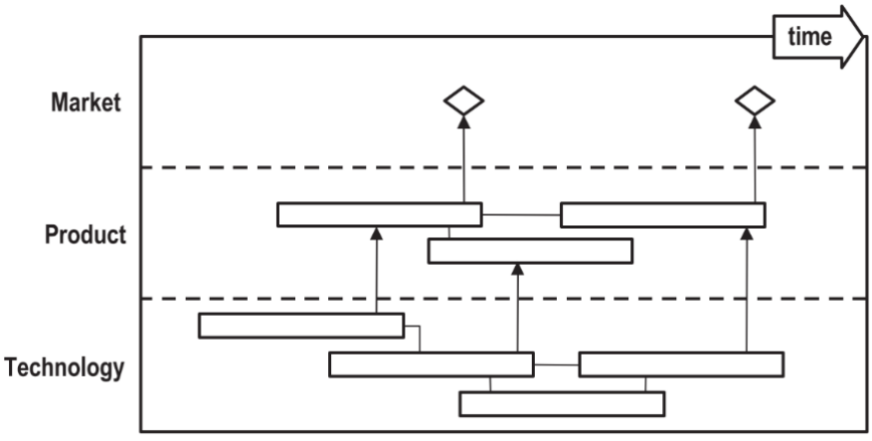


Figure 1. Generic technology roadmap (Phaal et al., 2004b).

While TRM was developed with product development in mind; it seems applicable to service-oriented firms too. It was used successfully in a service-oriented firm, i.e. the United Kingdom Royal Mail, to prioritise research activities and ensure technology considerations are integrated into business strategies (Wells et al., 2004). To date, this seems to be the only example of TRM being applied to services.

1.1 Problem statement and design goal

Engineering consultancy is a complex environment with dynamic teams composed of experts from different disciplines. These experts work together for short periods of time on different projects for different customers. As an engineering consultancy firm, it is complex to explore innovations when there are so many variables to take into consideration. A method like TRM would be very valuable for engineering consultancy firms, however, TRM has not yet been tested or applied in the engineering consultancy industry. The closest example is the application of TRM at United Kingdom Royal Mail as the postal services is a service-oriented firm, like the engineering consultancy.

The example of postal services, however, is of limited value for engineering consultancy industries since it provides a different service than the engineering consultancy. For one, the postal service is a continuous and controlled process. Once the logistics network is set up and the mail flows through that network every day, the network remains controllable. In contrast, engineering consultancy involves a large variety of unique problem contexts. Clients have unique requests, requiring tailored advice. Furthermore, unlike the controlled processes of postal services, engineering consultancy are often project-based. Due to these two main differences, the planning of innovations strategies for engineering consultancy firms requires that a TRM method is designed to fit this industry, ultimately helping engineering consultancy to better develop their innovation strategy.

Sweco is an engineering consultancy firm, its ‘transmission pipelines’ specialist group currently struggles to develop an innovation strategy, and is in need for a structured method to do so. Since TRM has never been used in an engineering consultancy context, Sweco provides a good case setting to design a new TRM method, and apply it with them to facilitate their efforts to create an innovation strategy.

In short, this study aims to design a TRM method which allows engineering consultancy firms to develop their innovation strategy.

1.2 Report outline

The report starts with an introduction into TRM. Once a general impression of TRM has been given, the methodology in chapter three will be discussed. In the methodology will be elaborate on the two design cycles in which the TRM method was designed. In chapter four, the first step of the first design cycle was taken, the problem investigation. Chapter five, the second step of the first design cycle, the designed TRM method designed for engineering consultancy firms is presented. In chapter six, the third and last step of the first design cycle, an attempt to verify the designed TRM method was done and the conclusion was drawn that another design cycle was required.

In chapter seven the second design cycle was entered, with re-investigation of the problem. In chapter eight, the second step of the second design cycle, a more detail TRM method was presented. In chapter nine, the third and last step of the second design cycle, the designed TRM method was validated by implementing it in the specialist group at Sweco. Chapter ten is the discussions in which the theoretical and practical implications, limitations and recommendation for future research, and the practical recommendations are given. Chapter eleven concludes the study. Chapter twelve contains the references.

2 Theoretical background and motivation

Technology is often associated with science and engineering, a tangible application of knowledge, which could be considered the ‘hard’ side of technology. The ‘soft’ side of technology is then the processes, knowledge networks, and organisational structures that support the application of science and engineering. The ‘soft’ side of technology development is just as important as the ‘hard’ side (Phaal et al., 2004b). TRM is such a ‘soft’ side method that can assist technology and product development (Kappel, 2001). This chapter discusses the theory of TRM.

2.1 Introduction to technology roadmapping

TRM is multi-purpose (Kappel, 2001) as it delivers a process and a product simultaneously. TRM supports technology management and planning (Kappel, 2001; Phaal et al., 2008). The technology roadmap, the product of TRM, is a visualisation of what is discussed during the technology roadmap development process. Its use is versatile; its primary function is planning. Besides planning, it functions as a way to present the innovation strategy to other teams or organisations. It can also be used to search for disconnections and misalignments between the organisation and market (Cosner et al., 2007).

Technology roadmapping, the process, can improve communication, both internally and externally (Kappel, 2001; Phaal et al., 2004b). The technology roadmap is a visual communication method “providing a coherent and holistic structure (a common language) within which the evolution of the business system and its components can be explored, mapped and communicated” (Phaal et al., 2008, p. 136). The technology roadmap removes disconnections and misalignments of members in an organisation, and increases collaboration within and between the teams since everyone inside the organisation has a greater shared purpose. It opens up cross-organisational communication channels as alignment is established within the organisation (Cosner et al., 2007). Through this alignment, for example, R&D personnel in the organisation know when to start developing a particular technique specific to a product. At the same time, management knows why engineers are requesting budgets to develop this technique. Simultaneously, people in the marketing department will know when to start preparing for the arrival of this new product. The power of TRM lies in its ability to connect resources to products and services and then to markets (Kappel, 2001; Kerr & Phaal, 2015; Phaal et al., 2001; Phaal et al., 2004b).

Due to its versatility, the TRM know many shapes and is infinitely customisable (Phaal et al., 2004a; Phaal et al., 2004b; Wells et al., 2004); however, there is a generic format. This format consists out of three layers: a market layer, product layer, and technology layer. These layers are stacked on top of each other, and all plotted along the same time axis, as seen in Figure 1 on page 5 (Phaal et al., 2004b).

Customising the designed TRM method to the organisation it is applied in, is important (Phaal et al., 2001). Failing to do so will result in a troublesome and unpliant technology roadmapping process. Gerdsri et al. (2010) state that the applied TRM method should match the organisation’s objectives and culture. Gerdsri et al. (2019) argue that the success of the applied TRM method depends on the individuals applying the tool, as they have to come up with the innovations, share information, and make the decisions.

The generic roadmap is just a starting point; each time an organisation uses the TRM method, it should be customised. Through customisation, TRM supports a wide range of business aims, such as product planning, exploration of new opportunities, resource allocation and management and improved business strategy and planning (Phaal et al., 2001). On top of that, each organisation is different, e.g. unique culture, business processes, available resources, technology types. Therefore, to fully use the roadmap’s potential, the method should be customised to suit the organisation’s needs (Kappel, 2001).

The TRM process, the method of constructing a roadmap. Kostoff and Schaller (2001) came up with three different categories: expert-based, computer-based, and hybrid. The expert-based approach requires a group of experts who develop a roadmap by identifying nodes, links, and relationships. The computer-based approach uses computers to analyse large sets of data. These datasets are then searched for structural relationships, and a roadmap is formed (Gerdsri et al., 2019). The hybrid form combines the approaches. The interaction between the experts remains whilst the subjectivity is reduced through computers (Gerdsri et al., 2019).

3 Methodology: the development of the designed TRM method

The goal of this study was to design a TRM method that allows engineering consultancy firms to develop their innovation strategy. Design science was chosen as the method to the systematically come to the objective of this study 'to design a TRM method for engineering consultancy firms to develop their innovation strategy'.

Design science consists of three steps: problem investigation, treatment design, and treatment validation. This chapter will describe how the designed TRM method was designed by following the design cycle.

3.1 Build-up of the study

This study uses two consecutive but different design cycles. The reason is twofold: first, the designed TRM method did not contain enough operational details for complete verification during the first design cycle. Therefore, a request for more operational detail was made. With this new goal, the second design cycle was entered shown in Figure 2. The second reason why there was a need for a second design cycle was that the second design cycle used a different validation method, technical action research (TAR), compared to the verification used in the first design cycle.

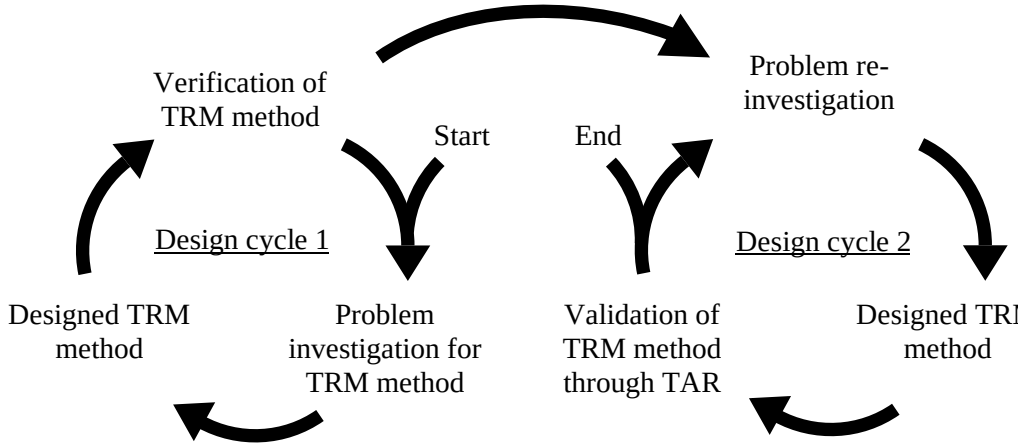


Figure 2. The two design cycles used in this study.

TAR tests a prototype of an artefact in the real world so the researcher can improve the designed artefact based on the experience. Simultaneously a client is helped as the artefact solves his or her problem. It is a very suitable method for this study as the designed TRM method designed in the second design cycle was considered ready for application outside of a research environment and only needed validation to be considered as a finished product.

3.1 The first design cycle

The three stages of the first design cycle will be elaborated on in the following three subchapters.

3.1.1 Problem investigation

To investigate the innovation problems described by Eriksson (2013), the researcher was part of an engineering consultancy firm for eight months. Conversations were held with twelve Sweco employees about their job descriptions, how their jobs changed over time due to innovations and their role in those changes. The employees came from both in and outside of the specialist group; this meant the researcher knew how this one team handled innovations and got a picture of how departments within Sweco were dealing with innovations and how the innovation was communicated between the departments. Questions that were asked during these conversations were regarding Sweco's current innovation strategy, i.e. How do you keep track of what is being developed inside your team? How do you keep track of industry-wide innovations? How are you notified about these innovations? Do these developments support each other? Is there a vision for the innovation strategy in your team or Sweco wide? Next to the conversations, the researcher also got to see four documents describing the plans for the upcoming year and the next five years. These documents were drafted up to provide some guidance to the members of the specialist group. In the case of the specialist group, these documents provided information on where the specialist group thought the transmission pipeline industry was heading and

where the opportunities lay for them. To better understand what was going on in the ‘transmission pipeline’ industry, where the specialist group was active, two webinars regarding digital standards in the pipeline industry were visited. Again, giving the researcher a better picture of industry digitisation standards.

Being part of the specialist group for eight months gave the researcher an insight into the technological standards in their industry, the innovations they were planning, and the process by which the innovation strategy was determined. These observations, the conversations, and documents led to the problem context, along with the stakeholder’s desires. Two of these desires were turned into stakeholder goals and used in the next cycle step.

3.1.2 Treatment design

In the first design cycle, the first step was to turn the goals from the different stakeholders into requirements. The stakeholder requires a property from the treatment; this is a requirement. So, the stakeholder goals were broken down and turned into the requirements presented in chapter 5.1 Requirements for the designed TRM method.

As a result of its worldwide use in different problem-contexts, different TRM schools have evolved. Six of these schools found in literature were compared based on the following six criteria to help the design process:

1. Data collection method. The method through which the data is collected before and during TRM.
2. Data processing method. The method through which the data is processed to eventually end up on the technology roadmap.
3. Method of forming the technology roadmap. The method through which the end product of TRM, the technology roadmap is made.
4. Research perspective. The reason to apply the TRM method is either to explain why things happened, retrospective, or to predict the future, prospective.
5. Size of the data set used in the designed TRM method.
6. Validation during the development of the school’s signature method.

These methods develop technology roadmaps through different processes. The criteria helped select, combine and develop a tailored TRM method that would result in an innovation strategy at an engineering consultancy firm.

3.1.3 Treatment verification

During the last stage of the first design cycle, the researcher verified the designed TRM method. The verification was performed to investigate whether the designed TRM method was ready for application in the real world. The researcher went over each requirement set in chapter 5.1 Requirements for the designed TRM method and checked whether it would be verified by the designed treatment.

As mentioned before, the designed TRM method contained too little detail about the operational phase to complete the verification. This called for a second design cycle.

3.2 The second design cycle

The second design cycle will be elaborated on in the following three subchapters.

3.2.1 Problem re-investigation

For the second design cycle, the problem was re-investigated by drafting additional goals that would be turned into requirements during the treatment design. These additional goals would be the basis of a successful validation at the end of the second design cycle. The goals were based on the findings of the verification of the first design cycle.

3.2.2 Treatment design

During the second design cycle, the goals from the problem investigation were turned into two additional requirements. With the additional requirements outlined, the designed TRM method was improved with operational details like the type of brainstorm tools and the hourly planning for all four workshops.

3.2.3 Treatment validation

The additional details made it possible to implement the designed TRM method in the real-world. Therefore, TAR was used during the second design cycle. The specialist group ‘transmission pipelines’ at Sweco served as a case study, which can be read in chapter 9.1 The implementation of the designed

TRM method in specialist group ‘transmission pipelines’ at Sweco. The specialist group consisted of seven people, all performing engineering consultancy work with different specialities like 3D design, hydraulic calculations, or engineering and policy advice. They were also responsible for their innovation strategy. The diverse engineering consultancy activities and the responsibility for their innovation strategy made the specialist group a fitting group to use the designed TRM method. As the researcher was already involved with the specialist group for five months before the workshops were due, the specialist group members and the researcher had built up a bond of trust that allowed the researcher to support the team with this change.

The treatment validation of the second design cycle starts with the evaluation of the implementation of the designed TRM method at the specialist group. Three participants of the workshops were interviewed. The questions were based on the requirements from chapter 5.1 Requirements for the designed TRM method and were meant to confirm whether the implementation of the designed TRM method at the specialist group was successful so it could be used to validate the TRM method. The questions were the following:

1. Did the designed TRM method facilitate the discussion about the impact of external influences and the organisation’s environment on the innovation strategy?
2. Did the designed TRM method facilitate the discussion about the impact of internal firm developments on the innovation strategy?
3. Did the designed TRM method facilitate the discussion on planning the innovation strategy?
4. Did the designed TRM method facilitate the formation of a roadmap that captures and visualises the information gathered during the workshops?
5. Did the designed TRM method facilitate the improvement of the team members internal communication and alignment?

The interviews were one-on-one interviews in a structured format. The five questions listed above were asked along with a request to explain their answers. The interviews were held online and transcribed, and parts of the interview were translated to English for citations. The complete interview guide can be found in Appendix D: Interview guide evaluation designed TRM method.

After the implementation of the designed TRM method was evaluated, it could be validated. First, the researcher validated the designed TRM method in the specialist group and the requirements set in chapter 5.1 Requirements for the designed TRM method and 8.1 Additional requirements for the designed TRM method were satisfied by the designed TRM method. Once the validation was completed, the conclusion regarding the research goal was drawn.

4 Design cycle one: Problem investigation

The first step in the design cycle is to investigate the problem. An extensive description of the problem context and design goal can be found in chapter 1 Introduction. The essential findings are repeated here.

Engineering consultancy firms have trouble balancing the exploration and exploitation of innovations. To help them find the right balance, planning these activities would be helpful as supposed to leaving it all to chance. TRM is method that has proven itself to be a great strategic planning tool in product-oriented industries. However, TRM has never been applied in engineering consulting firms to develop innovation strategies. The closest service-oriented application of TRM was in the United Kingdom Royal Mail. The problem definition was turned into the goal ‘to design a TRM method which allows engineering consultancy firms to develop their innovation strategy’.

Sweco is one of the two stakeholders of this study as they helped finance the performed research. The specialist group was the second stakeholder as they were the end-users of the designed TRM method. The specialist group wanted to be more innovative and be more innovative at a pace not connected to the client projects. The desire of the specialist group was defined as the following stakeholder goal: To improve innovation adoption by managing our innovation process. Sweco desired the specialist group to develop their business plan, including their innovation strategy and made a budget available. These non-billable activities were supposed to be done by the specialist group members during their non-billable hours, which was allowed to be as much as twenty per cent of their time. This desire by Sweco was turned into the stakeholder goal: The specialist group should develop their innovation strategy within this twenty per cent of non-billable hours.

5 Design cycle one: Treatment design, the designed TRM method

In this chapter, seven requirements were drafted based on the goals established in the previous chapter. Next, existing schools on TRM are systematically reviewed and compared based on six criteria from literature. From which a TRM method is designed which support engineering consultancy firms in the development of their innovation strategy.

5.1 Requirements for the designed TRM method

The goal of this study is to design a TRM method that allows engineering consultancy firms to develop their innovation strategy. These requirements were drafted up based on the goals of the stakeholders and should contribute to their goals:

1. The designed TRM method had to use or partially use qualitative data to develop the innovation strategy. Qualitative data is required because innovation strategies are very abstract; data for an innovation strategy does not consist of large sheets with numbers. Instead, it consists out of speculations of what could be. Additionally, as this is research is breaking new ground, qualitative data on this topic is easier processed than quantitative data and the large volumes it comes in. So, to stay within the scope of this study, qualitative data is the preferred type of data to develop the innovation strategy.
2. The designed TRM method uses some form of expert-based data processing. The expert-based approach made it more manageable than the hybrid approach to test and implement in the new context of engineering consultancy, as effects can be directly traced back to events in the workshops. Additionally, the expert approach fits the exploratory nature of an innovation strategy and the western culture where the new TRM method will be designed.
3. The designed TRM method requires the product ‘the technology roadmap’ that follows from the method to be made by the workshop participants. This further rule out the use of computers as designing a computer program that can make a technology roadmap is not per the goals of this study.
4. The designed TRM method should facilitate the discussion about the impact of external influences and the organisation’s environment on the innovation strategy. During the TRM workshops, external influences on the firm need to be considered.
5. The designed TRM method should facilitate the discussion about the impact of internal firm developments on the innovation strategy. Next to looking outward, TRM should also incorporate technological developments that are happening inside the organisation.
6. The designed TRM method should facilitate the discussion on planning the innovation strategy. The designed TRM method should make the participants prioritise the opportunities they want to pursue. The prioritisation needs to be done as the organisation might not have the resources available to pursue all opportunities (McCarthy et al., 2001). Next to resource availability, identifying misalignments and gaps ensures an organisation does not miss out on an opportunity because of an oversight in the technological resources – product – market chain (Phaal et al., 2001).
7. The designed TRM method should facilitate the team members internal communication and alignment. The underlying objective of the designed TRM method is to improve the internal communication and alignment of the participants (Wells et al., 2004). The designed TRM method should facilitate this improvement process.

5.2 Different schools of thought

As TRM can be used for different purposes, and processes people have created a wide variety of TRM methods for different applications resulting in different schools of thought. Park et al. (2020) distinguished six schools of thought: Cambridge practical school, Seoul school, Portland/Bangkok schools, Cambridge phenomenological school, Beijing school, and Moscow school.

The schools will be first briefly introduced, then compared based on six criteria found in literature that will help to compare the different schools: (1) data collection and (2) processing method are discussed, followed by (3) whom the technology roadmaps form, (4) the application reason, the (5) size of the data set used in the designed TRM method by the participants and (6) how the method was validated during its development. The numbers in the text correspond with the rows in Table 1 where an overview of the different schools is presented.

Cambridge practical school:

1. The data collection method is qualitative as the experts participating in the workshops are the source of the data, and a technology roadmap is formed from their knowledge.
2. Characteristic for this schools is the interactive, visual and tactile nature of the workshops during which the experts create the technology roadmap.
3. The Cambridge practical school has two workshop based plans: the 'fast-start' technology plan (T-plan) (Phaal et al., 2004b) and the strategic plan (S-plan) (Phaal et al., 2007). The T-plan is designed for product-technology development, but due to its customizability, it can also be used in a general strategic application (Phaal et al., 2004a; Phaal et al., 2004b). Phaal et al. (2004b) proposed several T-plan workshops as a reference; a typical roadmap takes four workshops of half a day. The S-plan is the first step in a product strategy process (Park et al., 2020) and was designed as a one-day large-scale multifunctional workshop, according to Phaal et al. (2007). The S-plan is designed to "support general strategic appraisal, and the identification and exploration of new strategic, innovation, and business opportunities." (Phaal et al., 2007, p. 5). The S-plan is less technology-focused and thus more usable for generic applications such as business unit, corporate, and sector applications (Park et al., 2020; Phaal et al., 2007). It is also more exploratory than the T-plan. In both plans, the participants form the technology roadmap during the workshops.

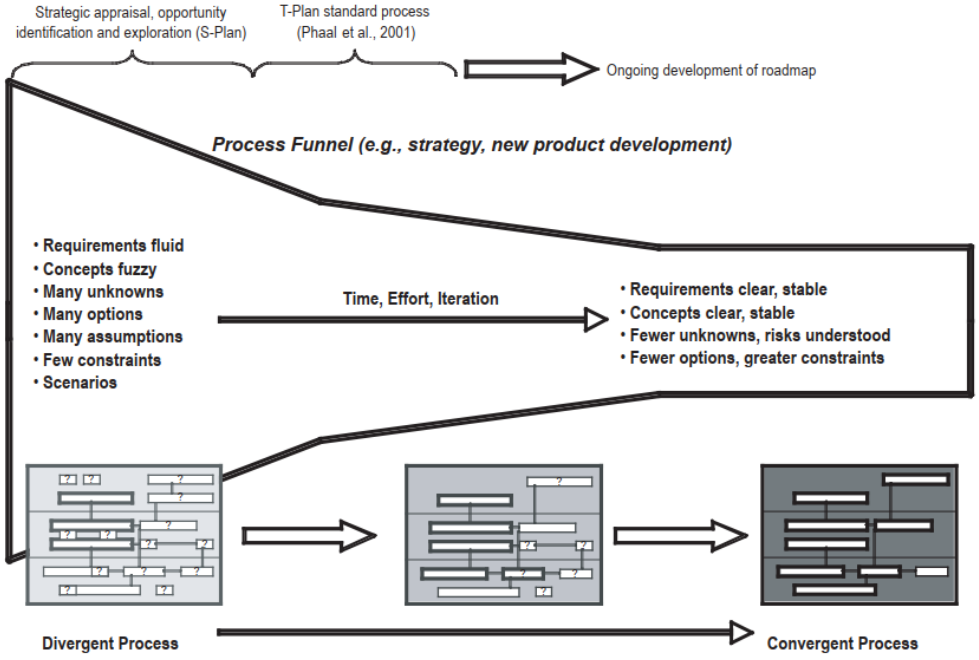


Figure 3. Roadmapping process according to Phaal et al. (2007)

4. The research perspective is practical.
5. The data set is considered small. The only data used in the technology roadmap has to be discussed during the workshops, limiting the amount of data used as input for the technology roadmap.
6. Due to its popularity, it has been thoroughly tested and has proven itself in a wide variety of industries (Park et al., 2020). In addition, an extensive set of successful workshops proofs the functioning of the method (Park et al., 2020).

Seoul school: The Seoul school is quite the opposite of the Cambridge school regarding its roadmapping approach.

1. The Seoul school focuses on developing software to make roadmaps instead of organising workshops. A software tool is preferred over the workshops, this has to do with culture. The practitioner's culture in Seoul and neighbouring countries is 'passive, soothed, contented, and quiet' (Park et al., 2020). This makes the required open and candid communication style found in the Cambridge school workshops difficult as it is not in the participant's culture.

2. The Seoul school uses raw digital data to form the technology roadmap; this has several benefits. The software allows a single person to make the technology roadmap. This person can contact experts and build the technology roadmap in the software.
3. The Seoul school makes the technology roadmaps digital. They did extensive research on the design of the elements used in the technology roadmaps as elaborate evidence is sought for elements of the technology roadmap like arrows, boxes, or the layers used (Son et al., 2015).
4. The research perspective is practical.
5. The databases are another benefit. These allow the technology roadmap to be based on a large amount of data. These databases can contain patents or describe science, technology, engineering, and end products. This is a more extensive data set than for instance the Cambridge practical school.
6. A limiting factor of the Seoul school is the lack of field testing of the developed methods; they are rarely field-tested and thus constantly subjected to uncertainty when used in real-world scenario's (Park et al., 2020). Moreover, an innovation strategy is not easily deciphered from data due to an innovation strategies abstract nature. On top of that, the Seoul school completely loses the group workshop element, which will make this school perform less when it comes to unifying the technology roadmap users.

Portland and Bangkok school: The Portland and Bangkok school focuses on integrating decision-making models and tools into TRM workshops (Park et al., 2020). An example is Technology Development Envelope (TDE), designed by Gerdsri (2007). In the TDE methodology, the Delphi method and Hierarchical Decision Modelling are combined to form the foundation for TDE. This foundation allows executive-level decision-makers to incorporate emerging technologies into developing technology strategies. N. Gerdsri shifted the focus of the research to the implementation of TRM in organisations (Gerdsri et al., 2010; Gerdsri et al., 2019; Gerdsri et al., 2009) to create the so-called 'Implementation-oriented roadmapping' (Park et al., 2020).

1. Information is gathered through a combination of workshops with participants from different levels of the hierarchy within the organisation, as well as through the methods that were added to TDE.
2. As the experts are gathered in a workshop environment to discuss data collected by computer, the school can be considered a hybrid when it comes to data processing.
3. In these workshops, the experts form the technology roadmaps on paper.
4. The research perspective is practical.
5. Due to the combination of expert-based workshops and the pre-workshop processing of data by computers, the size of the data set is large as data input is no longer restricted by the processing capacity of the experts in the workshops.
6. The Portland/Bangkoks school methods have been field-tested several times and are continuously improved, as Gerdsri et al. (2019) explored the issue of roadmap validity.

The Portland and Bangkok school shows how versatile TRM can be as they combine various other tools with TRM. More interestingly for the designed TRM method is the research done to integrate TRM into the organisation and make it part of the organisation. A successful implementation is of great importance to the success of the newly formed innovation strategy.

Cambridge phenomenological school: A group of researchers in Cambridge started to focus more on addressing research problems, developing TRM as a research tool, letting go of the development of products and services. It is designed to study the innovation dynamics of socio-technical transitions but can also be used for broader social phenomena (Park et al., 2020). The unique thing about this school is that it is designed to look at things retrospectively, whereas the other schools are all prospective.

1. The data collection method is both qualitative and quantitative.
2. Data processing is hybrid.
3. Participants make the technology roadmap.
4. The research perspective is scientific.
5. Data set size can be both small and large.
6. N/A

Beijing school: The Beijing and Moscow schools are new streams of TRM research, as the first publication came out in 2013. The Beijing school is based on bibliometrics both in developing the methodology and the roadmaps the methodology produces. For the creation of roadmaps, the Beijing school also incorporates qualitative, numeric, and textual data (Park et al., 2020). The Beijing school's approach is also used in real-world applications, as proven by many studies using real-world testing.

1. The data collection method is both qualitative and quantitative.
2. Data processing is hybrid.
3. Participants and the computer make the technology roadmap.
4. The research perspective is practical.
5. Data set size can be both small and large.
6. Field-tested

Moscow school: The Moscow school focuses on 'multiple futures' thinking. Other schools typically develop only one future (Park et al., 2020). Another characteristic of the Moscow school is their integrative nature to roadmapping; they combine bibliometrics (Vishnevskiy et al., 2015), 'wild cards and weak signals' (Vishnevskiy et al., 2016), and scientometrics (Saritas & Burmaoglu, 2016). These methods were often validated in Russian industries (Park et al., 2020).

1. The data collection method is both qualitative and quantitative.
2. Data processing is hybrid.
3. Participants and the computer make the technology roadmap.
4. The research perspective is practical.
5. Data set size can be both small and large.
6. Field-tested

Table 1. Comparison between the six different schools of thought along six criteria.

Dimension	**Cambridge practical school**	**Seoul**	**Portland/ Bangkok**	**Cambridge phenomenological school**	**Beijing**	**Moscow**
1. Data collection method (Qualitative <-> quantitative)	Qualitative	Quantitative	Both	Both	Both	Both
2. Processing of collected data based on Kostoff and Schaller (2001)	Expert-based	Computer-based	Hybrid	Hybrid	Hybrid	Hybrid
3. Method of forming the technology roadmap	Participants	Computer	Participants/computer	Participants	Participants/computer	Participants/ computer
4. Research perspective	Prospective/ Practical	Prospective/ Practical	Prospective/ Practical	Retrospective/ Scientific	Prospective/ Practical	Prospective/ Practical
5. Size of data set (Small data <-> large data)	Small data	Large data	Both	Both	Both	Both
6. Method validation	Recursive field test	In-house alpha test	Field test	N/A	Field test	Field test

The first comparison criterium is the data collection method. For an innovation strategy qualitative data collection method is more suitable as the information required to develop an innovation strategy is most often found as qualitative data. The Cambridge practical, Portland/Bangkok, Cambridge phenomenological, Beijing and Moscow school use qualitative data collection methods. Unlike the Seoul school, which is therefore less relevant for this study.

The second comparison criterium is the data processing method. Qualitative data collection methods lead to qualitative data processing. A combined method often entails, like the Portland/Bangkok school, the use of quantitative data analysis in between workshops. The qualitative data analysis then happens

during the workshops. The Cambridge practical school fully relies on the expert's abilities to come up with and process the data during the workshops. The interactive group workshops that, for instance the Cambridge practical school provides are ideal for developing an innovation strategy. An innovation strategy is abstract and hard to define topic that makes effortless communication and exchanging thoughts essential. Communication is critical when developing an innovation strategy; the workshops allow for discussion with people of similar high expertise on the topic of the innovation strategy.

The third comparison criterium is the method of forming the technology roadmap. For the designed TRM method communication during the formation of technology roadmap has a high priority. Therefore, making design choices that lead to more communication are given president over school that might provide more efficient methods of developing the technology roadmap but lead to less communication in the process. The Cambridge practical school lets it users physically form the roadmap, but also the Portland/Bangkok school is known to let the participants form a physical roadmap.

The fourth comparison criterium is the research perspective the school has. The Cambridge phenomenological school has a retrospective scientific research perspective which is not relevant when developing a prospective innovation strategy. The Cambridge phenomenological school will therefore be no longer considered in this study.

The fifth comparison criterium is the size of the data set. A downside of only using the workshops to process data, like the Cambridge practical school does, is the size of the data set used in the development of the innovation strategy. That becomes rather small compared to other methods that do allow for quantitative data analysis in between workshops.

The sixth comparison criterium is the validation of the method. The Cambridge practical school has the largest number of field tests on its name, making it a proven and successful method. The Portland/Bangkok, Beijing and Moscow school also have been proven in numerous field tests and can therefore be considered validated as well.

Next to the six criteria, there are also some unique characteristics through which the schools differentiate themselves. The Portland/Bangkok school this is the research on implementing the technology roadmap into the organisation. The Portland/Bangkok school developed TRM methods that are context-specific. Context-specific roadmaps are implemented with less effort as they are customised to the organisation. The findings regarding the implementation of a technology roadmap will be used in the designed TRM method as every stage of the designed TRM method can influence the acceptance of the designed TRM method by the people in the organisation.

The Beijing school uses more extensive and complex methods to develop the technology roadmap than the Cambridge practical school and the Portland/Bangkok school. The extra complication is not required for the successful development of an innovation strategy; that is why the Beijing school will not be used in the remainder of this study. The Moscow school focuses on multiple futures, as the research of TRM in engineering consultancy is still in an exploratory phase; developing a TRM method that can deal with multiple futures would add unneeded complexity. That is why elements of the Moscow school will not be used in the designed TRM method.

- To conclude, the Cambridge practical school by Phaal et al. served as a prime example for the design TRM method, as the expert-based workshops fit the requirements. Elements from the Portland/Bangkok school by Gerdsri et al. were also considered and taken into account due to the research performed by the Portland/Bangkok school in the implementation of TRM in an ongoing business.

5.3 Designed TRM method: The three phases of the designed TRM method

The Cambridge practical school and the Portland/Bangkok school divide their TRM methods into three phases. The T-plan by the Cambridge school (a) planning, (b) roadmapping, and (c) roll-out (Phaal et al., 2004b). Implementation-oriented roadmapping by the Portland/Bangkok school consists of (a) the firm getting to understand the basic knowledge, requirements, and approaches about roadmapping; (b) the workshops themselves are conducted, and information is captured in a roadmap; (c) roadmapping becomes part of the organisation and is used as a strategic planning tool (Gerdsri et al., 2009). The designed TRM method will also use the three-phase structure, as shown in Figure 4. Since this study focusses on the design of the TRM method for engineering consultancy firms to develop their innovation strategy, the implementation phase of will be left out of this study.

Figure 4. The three phases the designed TRM method will consist of.

- Concluding, the designed TRM method consists out of two phases as the implementation phase is out of the scope of this study.

5.4 Designed TRM method: The preparing the workshops phase

The workshops are just part of the designed TRM method; the workshops also need to be prepared. The first phase, 'planning' as Phaal and colleges call it and the 'initiation stage' as Gerdsri and colleges call it, is about preparing the workshops

In the preparing the workshops phase of the designed TRM method, the following items need to be determined every time before the designed TRM method is applied:

- Ownership of the business problem: There must be a person appointed as the one responsible for the business purpose and the business problem (Phaal et al., 2004b). This person must understand that the innovation strategy that will follow from the designed TRM method will help him/her achieve the business purpose and solve the business problems. Additionally, this person can take responsibility for the TRM process and implement the technology roadmap.
- Scope: At the start of the discussion, a clear set of boundaries must be determined (Kerr & Phaal, 2015). These boundaries determine which level in the organisation the technology roadmap and thus the innovation strategy is for, i.e. a program or project, a business unit, or the whole organisation. By setting the boundaries, it is known where the technology roadmap, i.e. the innovation strategy, will interact and is leading with other parts of the business.
- Focus: The reason why there is a need for a roadmap needs to be determined (Phaal et al., 2004a). In the case of the designed TRM method, this will be developing an innovation strategy.
- Aims: The goals and objectives an organisation hopes to solve by using TRM, needs to be determined. Typically, overall business needs play a role here, i.e. improve communication (Gerdsri et al., 2010).
- Resources: The time, money, and the number of people the organisation is willing to devote to the designed TRM method need to be determined to ensure the organisation is ready to see the process through to the end (Phaal et al., 2007).
- Participants: The development of a high-quality roadmap depends on the participants making the technology roadmap, providing expert knowledge (Kostoff & Schaller, 2001). The group of participants should be balanced in knowledge about the technical side and the business side; this means participants originate from different layers of the organisation (Gerdsri, 2007; Gerdsri et al., 2009; Phaal & Muller, 2009; Phaal et al., 2012). For developing an innovation strategy, the group will indeed be mixed as product or service development is considered from development till introduction to the market, the entire organisation is involved. Apart from the knowledge, the group dynamic is at the foundation of Cambridge practical school (Phaal et al., 2007; Phaal & Muller, 2009) and Portland/Bangkok school (Gerdsri, 2007; Gerdsri et al., 2009).

Ensuring an open and friendly environment will hugely benefit creativity and thus generate a complete technology roadmap. So, selecting the right people to join the workshop is very important and should be done with careful thought.

- Information: Phaal and Muller (2009) raise awareness for the level of granularity. The level should not contain too much detail as this might overcomplicate the technology roadmap and constrain participants' thinking. On the other hand, too little detail would mean a vague or unclear roadmap that is of no use to the organisation. According to them, the level of granularity should be such that the scientific efforts align with the sector trends (Phaal & Muller, 2009). Decide the required level of granularity and share this with the participants before starting the workshops.

The architecture of the technology roadmap should align with the process. Doing so will ensure the technology roadmap can capture and structure the generated knowledge during the workshops (Phaal et al., 2004a). The participants finalised the architecture during the last workshop due to newly gained insights during the workshops.

In case the organisation would like to use TRM more often, this would then be the time to educate one team member to gain enough knowledge of TRM to become a TRM expert. These participants would become the so-called TRM experts. The education of the TRM experts consists of learning how to prepare and plan TRM workshops. The TRM experts can help the moderator or make him/her even obsolete as the team has the knowledge in-house. The TRM expert also becomes the driving force of the TRM initiative, ensuring its continuation (Gerdsri et al., 2009).

- In conclusion, by combining the 'planning' phase from Phall and colleges and the 'initiation stage' by Gerdsri and colleges, the preparing the workshops phase for the designed TRM method for engineering consultancy took shape. The preparing the workshop phase aims to determine the reason to use TRM and customise and prepare accordingly.

5.5 Designed TRM method: The workshops

Phaal et al. (2007) referred to the next phase as the 'roadmapping' phase. Gerdsri et al. (2010) describe this phase as the 'development stage', where information is collected, and the workshops are organised. Both methods construct the technology roadmap during a series of workshops. Phaal et al. (2004b) emphases the importance of the process, "The roadmapping process is often said to be as important as the technology roadmap itself, owing to the benefits associated with the discussion and learning that are associated with the development of a roadmap." (p. 31). Cosner et al. (2007) agree with the statement that communication and understanding are improved, even if no action is deliberately taken. That is why the designed TRM method uses workshops, as sharing ideas and thoughts is crucial when developing an innovation strategy.

The Cambridge practical school knows two plans: The S- and T-plan. The S-plan is derived from the T-plan and is essentially a strategy-focused version of the T-plan (Park et al., 2020). The S-plan is a roadmap that precursors the T-plan, as shown in Figure 3 on page 13. If the opportunity still looks promising, the technology roadmap made during the S-plan workshop can be further developed using the T-plan process (Phaal et al., 2007). The S-plan workshop is a one-day workshop consisting out of four parts: capturing the strategic landscape, identifying innovation opportunities, exploring priority opportunities, and the way forward (Phaal et al., 2007). The standard T-plan consists of four half-day workshops. Table 2 shows the four workshop days for the T-plan in order with a description of the aim for each day. Workshop one focuses on the market, the goal of the workshop is to figure out what the market wants, and needs are. Workshop two tries to find a product for the market. Workshop three is concerned with the making of the products from workshop two. In the last workshop, the market, product life-cycle and technology development are planned in the technology roadmap. The topics that are treated in the workshops have to be customised to the organisation's needs using it.

Table 2. Standard T-Plan structure (Phaal et al., 2004a)

Workshop 1 Market	Workshop 2 Product	Workshop 3 Technology	Workshop 4 Roadmapping
• Performance dimensions • Market/business drivers • Prioritisation • SWOT • Gaps	• Product feature concepts • Grouping • Impact ranking • Product strategy • Gaps	• Technology solutions • Grouping • Impact ranking • Gaps	• Linking technology resources to future market opportunities • Deciding the way forward

The S-plan is concerned with exploring strategies, whereas the T-plan focuses on the actual development of a strategy. The goal of the designed TRM method was to develop an innovation strategy for an engineering consultancy firm. The T-plan is thus the most appropriate plan to use as a basis for a TRM method to develop an innovation strategy with.

As a result, Table 3 shows the four workshops for the designed TRM method to develop the innovation strategy of engineering consultancy firms. Day one is focused on the *why?* of the innovation strategy. Participants have to formulate *why* they are investing the time and effort into developing an innovation strategy in the first place. If the *why* is clear to all participants, they can all work independently towards a shared goal.

Table 3. Workshop plan for the designed TRM method for engineering consultancy firm to develop their innovation strategy.

Workshop 1 Why?	Workshop 2 What?	Workshop 3 How?	Workshop 4 When?
• External motives for innovation • Internal motives for innovation • Prioritising innovation drivers • Gaps	• Service feature concepts • Grouping • Prioritising via grid analysis • Service strategy • Gaps	• (Technology) solutions • Grouping • Prioritising via grid analysis • Gaps	• Linking (technology) resources to future market opportunities • Discussing the implementing of the technology roadmap

The *why* of the innovation strategy is considered by taking inventory of the internal and external motives to innovate. According to Phaal and Muller (2009) the external motive should be sought at the customer. It prevents the participants from focussing too much on technological issues. Therefore, this workshop uses the experience the experts have with the customers as input for this workshop. The other input the experts have to deliver is the experience they have performing their job. The experiences the users have in performing their jobs are used to find the internal motives to innovate. All the motives are grouped into innovation drivers. The innovation drivers are prioritised, it helps the participants decide the priority of all the different goals or targets they can innovate towards. This prioritised list is the output of this workshop.

Workshop two, the focus is on the *what?* of the innovation strategy. The *what* are the things that are going to innovate, this can be anything from a product to a service to how the employees of the organisation treat the customers. The input for this workshop is the different features that make up the services the engineering consultancy firm offers to its customers. By first looking at individual features that can innovate and only then grouping them by theme, the participants are forced to let go of the products and services they are currently offering. These themes will be referred to as innovation elements. Once they are prioritised, are the output of this workshop.

The grid analysis allows for easy insight into which innovation elements fulfil innovation drivers. Once filled out, the innovation element with the highest priority was calculated. Table 4 shows the grid used in the grid analysis. Each participant had to fill in whether he or she thinks the innovation element fulfils the innovation driver; if that is the case, a ‘1’ is filled into the table otherwise, a ‘0’ is filled in. The table from each participant is summed and multiplied with the dot voting session score from workshop 1 – Why?. Summing the row of each innovation element will give the priority score of each innovation element.

Table 4. Grid used in de grid analysis.

	Innovation driver 1	**Innovation driver 2**	**Innovation driver …**	**Priority score**
Dot voting session score	a	b	c	
Innovation element 1	= sum(0 or 1 by each participant) * a	= sum(0 or 1 by each participant) * b	= sum(0 or 1 by each participant) * c	= sum(row3)
Innovation element 2	= sum(0 or 1 by each participant) * a	= sum(0 or 1 by each participant) * b	= sum(0 or 1 by each participant) * c	= sum(row4)
Innovation element …	= sum(0 or 1 by each participant) * a	= sum(0 or 1 by each participant) * b	= sum(0 or 1 by each participant) * c	= sum(row5)

The end of every workshop is used to check its alignment with the previous workshops. The last thing to do is to look back at the workshop and see if something is missing. If there is a product or service lineup gap, this can be discussed and fixed.

In workshop three *how?* the innovation elements are broken down into different resources, i.e. skills, knowledge, or technological advancements and are checked against what is present in the organisation and what needs to be developed. The input requested from the participants for this workshop are solutions that will make the development of the innovation elements possible.

The grouping is done by gathering resources with the same theme. Grouping the resources makes it possible to do the grid analysis. The grid shows which resources are most important according to the participants. Again, after a grid analysis a gap analysis is performed. The output of the third workshop are the prioritised resources.

In workshop four *when?* the participants create the technology roadmap. The output of the previous three workshops will serve as input for this workshop, along with the planning experience of the participants. The innovation drivers, elements and resources are put on a timeline, creating the technology roadmap containing their innovation strategy. Next to creating the technology roadmap, during this workshop the implementation of the technology roadmap is discussed. Here, the participants plan how they will execute the newly created innovation strategy. If the organisation has decided to make TRM part of ongoing business, the participants also need to decide how to keep the technology roadmap up to date. The output of this fourth and final workshop is the technology roadmap containing the innovation strategy. Figure 5 shows an overview of all the in- and outputs of the workshops.

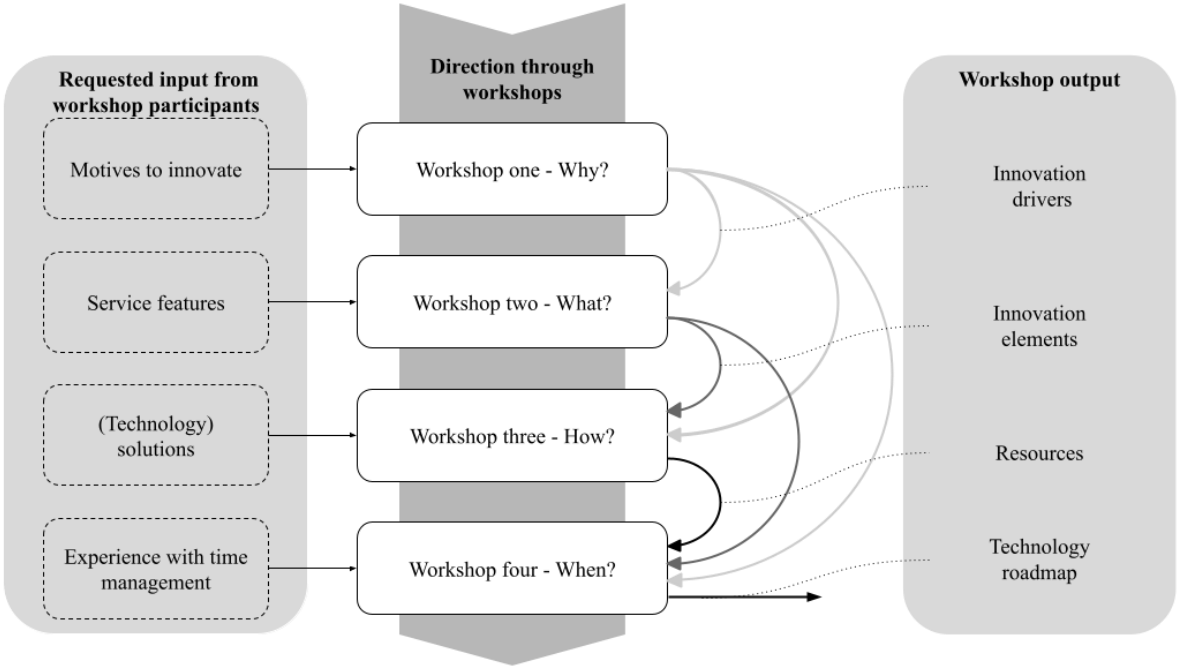


Figure 5. Overview of the in- and outputs of the workshops.

After the workshop is finished, Phaal et al. (2004a) recommend a post-workshop meeting with participants to review the outcomes. Often, some of the information on the technology roadmap is still dubious, and several gaps probably need to be addressed (Phaal et al., 2012). Therefore, these gaps and the questionable information on the technology roadmap are addressed in this post-workshop meeting.

The outcome of the workshops is heavily dependent on the participants (Phaal et al., 2001). Cosner et al. (2007) mention that participants have "to see the value produced for the corporation by their contributions to the roadmaps. […] If the benefit to their organisation is unclear, their support will be lukewarm at best." (p. 36). The knowledge they bring (Gerdsri et al., 2010) and the knowledge they capture during the sessions (Wells et al., 2004) determine the quality of the innovation strategy. The key to capturing quality knowledge is creating an atmosphere for sharing by inviting people that stimulate open communication during the workshops (Wells et al., 2004).

The workshops also play a vital role when it comes to improving communication. During the workshops, communication is improved using common frameworks; the tools used in the designed TRM method to develop an innovation strategy all the participants agree with (Kappel, 2001; Phaal et al., 2004a). Furthermore, by gathering participants from all parts of the organisation, cross-organisational channels are opened (Cosner et al., 2007).

- Summarising, the T-plan workshop structure from the Cambridge practical school by Phaal et al. was used as a basis for the framework for the designed TRM method for engineering consultancy firms to develop their innovation strategy. The workshop's goal is to develop the technology roadmap and improve and align the workshop participants communication.

5.6 Designed TRM method: The technology roadmap architecture

The technology roadmap architecture for the innovation strategy for engineering consultancy firms is based on the generic technology roadmap architecture. The generic roadmap consists of three layers. Each layer provides input for the next layer (Cosner et al., 2007). Phaal and Muller (2009) recommend a high 'de-coupling' of the layers, meaning the layers are distinctively unique. The time is represented horizontally from left to right; a clear evolution should be visible through a layer. The organisation's evolution through a layer will result in the layers being the 'chapters' of the innovation strategy; the entire technology roadmap should tell the 'story' of how the innovation strategy will be developed.

In a generic roadmap, Phaal and Muller (2009) point to three distinctive layers:

1) The top layer contains the goals and purposes of the innovation strategy. The goals and purpose of the innovation strategy consist of input from the external markets, industry trends and drivers, and internal business trends, milestones, objectives, and constraints. This layer can be thought of as the 'know-why', stating the goals and purpose of the innovation strategy to corroborate the effort of developing an innovation strategy.
2) The middle layer is the response to the top layer, resulting in products and services that create value for customers and other stakeholders. This layer can be considered the 'know-what', presenting what will innovate in the innovation strategy.
3) The bottom layer houses all the resources needed to develop the elements in the layer(s) above, i.e. technology, skills, competencies, finance, partnerships, or facilities. This layer contains the 'know-how' of the innovation strategy.

The layers and the separation between the layers should be clear. Within the layers, there are sublayers, as indicated in Figure 6. The participants of the workshops will fill each sublayer with a certain theme that come forth from the tools. Phaal and Muller (2009) recommend a maximum of 5–8 sub-layers per layer.

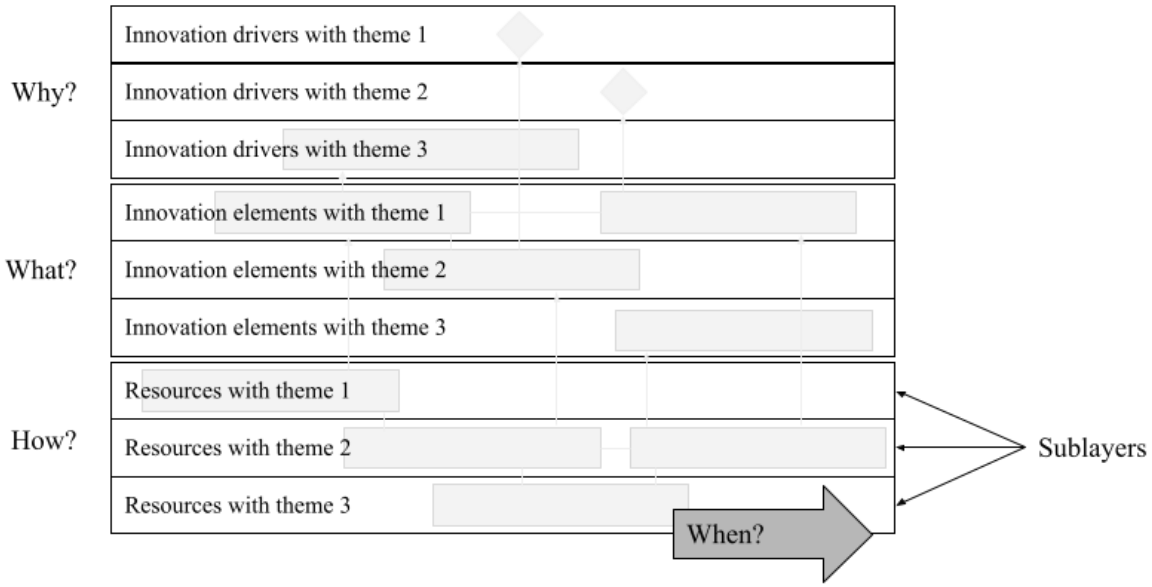


Figure 6. Architecture of generic roadmap of the designed TRM method with indication of sublayers.

The connections between elements over the different layers are clearly shown through one headed arrows as seen in Figure 8 on page 23 (Phaal et al., 2004b). However, the connection and causal relationship between layers are not as clearly depicted in the technology roadmap as the connection between the elements. A 'linked analysis grid' can visualise the causal relationships between the layers, as seen in Figure 7 (Phaal & Muller, 2009).

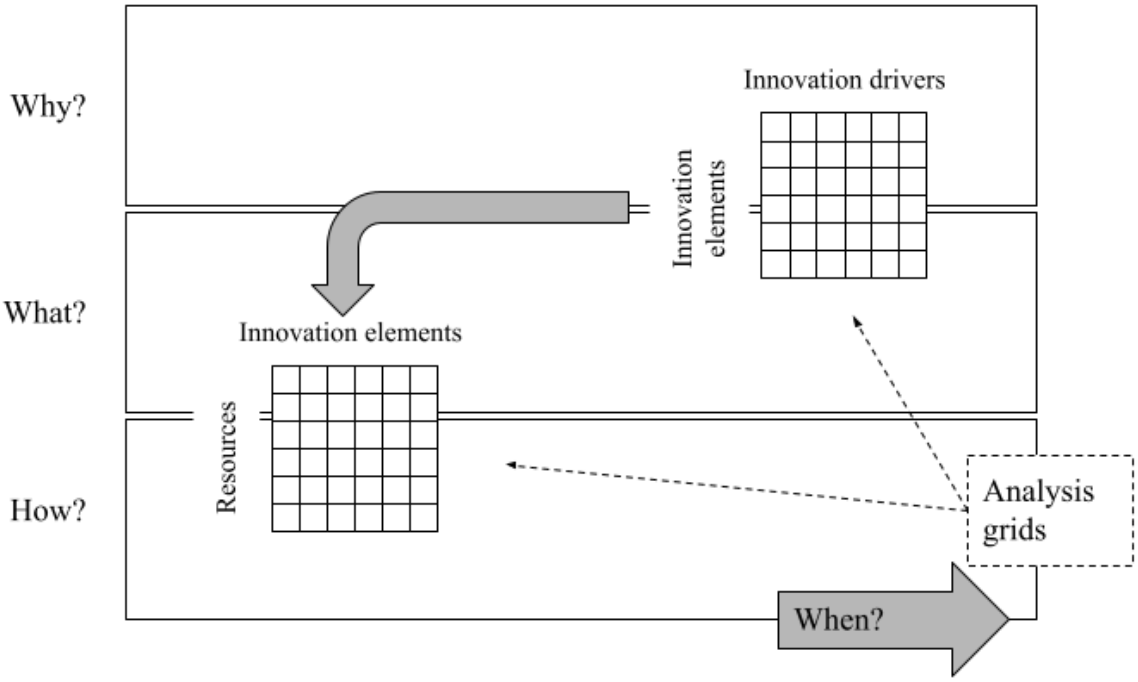


Figure 7. Linked analysis grids to help understand relationships between the layers (Phaal & Muller, 2009).

The last aspect of the technology roadmap is the horizon axis, which represents time. Phaal and Muller (2009) suggest five domains/horizons to incorporate into a technology roadmap; these five

domains are also used for the designed TRM method as it is a perfect timeline for engineering consultancy firms:

1. The past and present.
2. Short-term: This is one year in advance, and the most important output of the technology roadmap as concrete plans and actions will follow from this horizon.
3. Medium-term: This is a three-year horizon, describing the strategic planning horizon and highlighting the broader direction while still influencing the short-term decisions and plans.
4. Long-term: Typically, this is a ten-year timeframe. It bridges the gap between the medium strategy and the vision or organisational goals. The long-term horizon explores technology, business, and the market in the long term. It provides the opportunity for the organisation to capture these trends early on and allow them to influence their current decisions and plans.
5. Vision: it is essential to know where the organisation ultimately want to be heading.

Kerr and Phaal (2015) emphasise the importance of a good visual narrative in the technology roadmap by conveying a sense of direction in the technology roadmap and reading it like a story. They argue that this is done with a narrative sequence, a storyline, and narrative contrast, which are the critical points where change is evident or decisions are made.

The technology roadmap should fit on one piece of paper; this helps with the communication and forces the workshop participants to focus on the key issues. Fitting it on a single piece of paper will also help implement roadmapping into the organisational structure, as updating the technology roadmap can be done more efficiently (Phaal et al., 2008). A technology roadmap that is efficiently updated can keep up with the fast pace of business, technology and innovations (Phaal et al., 2008).

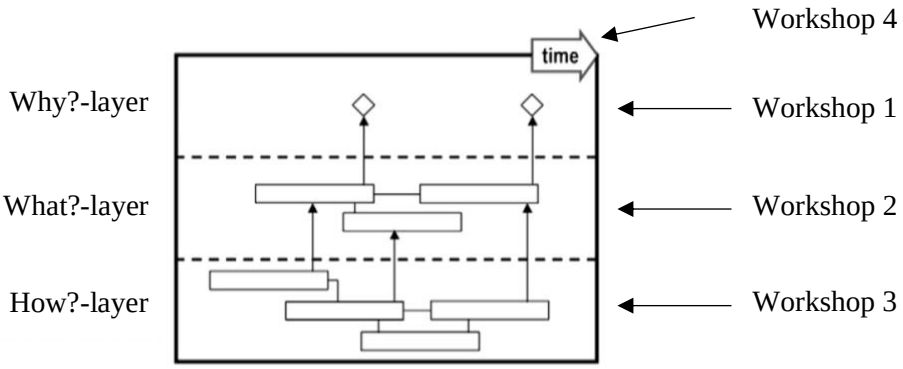


Figure 8. Visualisation of link between workshops and the technology roadmap.

For the architecture of the technology roadmap of the designed TRM method, the decision was made to start with three layers; a why-layer, a what-layer and a how-layer. Figure 8 shows the link between the workshops and the architecture of the technology roadmap. The why-layer focuses on the motivation to innovate, the drivers that propel the innovation. The what-layer is concerned with making the why-layer happen through products and services. The last layer, the how-layer, will contain skills, technologies, knowledge, and partnerships. The elements from the how-layer will form the what-layer. These three layers are presented on a single timeline, and the connection between the layers is shown via arrows.

5.7 Implementing technology roadmapping

The last phase is the ‘integration stage’ (Gerdsri et al., 2010) or ‘roll-out’ (Phaal et al., 2007). According to Gerdsri et al. (2010), TRM is integrated into ongoing business operations in the integration phase. Phaal et al. (2004b) agree with him, stating that organisations can choose to let the TRM form their strategy and planning process.

Implementation is, however, out of the scope of this study. Appendix B: TRM implementation contains information about implementing TRM in ongoing business due to its importance. The designed TRM method for engineering consultancy is designed to accommodate the recommendations done in Appendix B: TRM implementation.

Chapter five in short:

- The Cambridge practical school by Phaal et al. served as a basis for the new TRM method. It was complemented by the Portland/Bangkok school by Gerdsri et al., with elements of 'Implementation-oriented roadmapping'.
- The workshops in the designed TRM method are designed to produce a technology roadmap containing the innovation strategy and, in the process, improve communication and alignment between team members.
- The designed TRM method for engineering consultancy firms to design their innovation strategy will have four half-day workshops.
- The architecture of the technology roadmap for the innovation strategy of an engineering consultancy firm would consist of three layers; a why-layer, a what-layer and a how-layer on a single timeline.

6 Design cycle one: Verification of treatment

The designed TRM method was verified to see if all the requirements were met. In chapter 5.1 Requirements for the designed TRM method, seven requirements for the designed TRM method were drawn up according to the stakeholder goals. These seven requirements were checked by the researcher to see if the designed TRM method would be verified.

1. The first requirement was that *the designed TRM method had to use or partially use qualitative data to develop the innovation strategy*. As described in chapter 5.5 Designed TRM method: The workshops the designed TRM method prescribes workshops with experts. These experts are the primary data sources to develop the innovation strategy. Thus, this first requirement is verified as the primary data source required by the designed TRM method will be a qualitative source.
2. The second requirement is that *the designed TRM method uses some form of expert-based data processing*. Chapter 5.4 Designed TRM method: The preparing the workshops phase describes how experts must be carefully selected to participate in the workshops. During the workshops, these experts are thought to constantly discuss information and data and exchange knowledge to create new insights for the innovation strategy by looking at and manipulating the data through different tools. The data is thus processed by the experts present on the workshops, verifying requirement two.
3. The third requirement *requires the product 'the technology roadmap' that follows from the method to be made by the workshop participants*. The last workshop in the designed TRM method is devoted to visualising the technology roadmap which contains the innovation strategy. The visualisation is done by the participants, as described by chapter 5.6 Designed TRM method: The technology roadmap architecture, verifying the third requirement.
4. *The designed TRM method should facilitate the discussion about the impact of external influences and the organisation's environment on the innovation strategy.* The designed TRM method reserves time in the first workshop, as described in chapter 5.5 Designed TRM method: The workshops to discuss external motives to innovate. The goal is to look outside of the organisation to, for instance, to customers, suppliers or competitors to see what they would like to see changed or what they would perceive as positive in the engineering consultant's innovation strategy. Concluding, the designed TRM method verified the fourth requirement.
5. *The designed TRM method should facilitate the discussion about the impact of internal firm developments on the innovation strategy.* The designed TRM method, as described in chapter 5.5 Designed TRM method: The workshops also reserved a time slot for discussing the impact of internal firm developments on the innovation strategy. First, during workshop one, the participants can discuss internal motives to innovate. The goal is to look inside the organisation to find motives from within the organisation to innovate. So, the designed TRM method verified the fifth requirement.
6. *The designed TRM method should facilitate the discussion on planning the innovation strategy.* During the last workshop day, day four, of the designed TRM method, as described in chapter 5.5 Designed TRM method: The workshops, the participants have to make the technology roadmap which visualises their innovation strategy. The technology roadmap requires them to put all the innovation activities in relation to each other, making it obvious when activities take place, overlap or are not ready for the next step. Once the technology roadmap is finished, the planning is finished; verify the sixth requirement.
7. *The designed TRM method should facilitate the team members internal communication and alignment.* Although the workshop-based structure of the designed TRM method gives plenty of opportunity to the participants to improve their internal communication. It cannot be reasoned that the designed TRM method will indeed deliver the necessary improvement in the internal communication and alignment of the team members to verify this requirement. Therefore, the seventh requirement cannot be verified with what is currently known about the designed TRM method.

6.1 Verification conclusion of designed TRM method

Six out of the seven requirements could be verified. The seventh requirement requires more detail about the operational phase and an application of the designed TRM method in order to, without doubt, conclude that the designed TRM method is indeed capable of verifying all seven requirements. Therefore, a second design cycle is required.

7 Design cycle two: Problem re-investigation

As concluded in subchapter 6.1 Verification conclusion of designed TRM method, the designed TRM method required more detail in the operational phase to be verified. Therefore, a second design cycle was entered to add more details and reach the desired result. The second design cycle used TAR to validate the designed TRM method through an application in the real world.

During the second design cycle, the stakeholders and their goals were directly carried over from the first design cycle. The problem investigation from the second design cycle will add an additional design goal, which is ‘to design a ready-for-application-TRM method for engineering consultancy firms to develop their innovation strategy’.

8 Design cycle two: Treatment design, the designed TRM method

The new research goal drafted in chapter 7 Design cycle two: Problem re-investigation required additional requirements. The additional goal was ‘to design a ready-for-application-TRM method for engineering consultancy firms to develop their innovation strategy’. After the new requirements are drafted up, the designed TRM method will be re-designed and expanded with more operational details to pass validation.

8.1 Additional requirements for the designed TRM method

The seven requirements drafted in chapter 5.1 Requirements for the designed TRM method still needed to be satisfied by the designed TRM method made during the second design cycle. The new goal drafted up in chapter 7 Design cycle two: Problem re-investigation was expressed as the following two requirements:

8. The designed TRM method should prescribe what needs to happen during the workshop on an hourly basis.
9. The designed TRM method should specify the tools used to guide the discussions.

8.2 Designed TRM method: the preparing the workshops phase

The first step is to establish the parameters ownership of the business problem, scope, focus, aims, resources, participants, and level of detail. The business problem owner should establish these parameters before the TRM workshops as they will serve as a starting point.

Before the workshops, the participants should be informed about what will happen during the TRM workshops and how these workshops build onto each other. This session takes approximately 30 minutes. The session contains an explanation of the four workshops and their topics. The session does not make the participants TRM experts as too little detail about TRM is treated; the session is purely to inform them about what is to come. It is essential to discuss the first draft of the workshops' scope, goal, and aim drafted up by the business problem owner as the participants can raise any objections. So, the participants' objections or problems can be fixed before the workshops start.

If the organisation wants to use TRM more often, this would be the time to educate a TRM expert. Educating a TRM expert does take time, so the organisation has to be willing to invest the time. A TRM expert knows how to prepare the workshops, customise the designed TRM method for the required purpose and will keep watch during the workshops ensuring the tools are used correctly, and the participants are working towards the desired goal in each of the workshops.

8.3 Designed TRM method: The workshops

The designed TRM method uses the TRM workshop plan presented in Table 5. The plan is expanded with more operational details in the following five subchapters.

Table 5. Copy of workshop plan for TRM method for engineering consultancy firm to develop their innovation strategy as presented in chapter 5.5.

Workshop 1 Why?	Workshop 2 What?	Workshop 3 How?	Workshop 4 When?
• External motives for innovation • Internal motives for innovation • Prioritising innovation drivers • Gaps	• Service feature concepts • Grouping • Prioritising via grid analysis • Service strategy • Gaps	• (Technology) solutions • Grouping • Prioritising via grid analysis • Gaps	• Linking (technology) resources to future market opportunities • Discussing the implementing of the technology roadmap

The first three workshops were designed to be hosted online, and the last one was designed to be hosted physically. Hosting online workshops meant avoiding discussions with more than three people, having regular breaks, and ensuring that information was captured and stored in a usable format.

8.3.1 Online workshops

Online workshops call for different communication tools. In the case of the designed TRM method, a communication tool where the participants can form their own groups is advised; this saves the moderator the trouble of dividing the group and putting the participants in different virtual rooms.

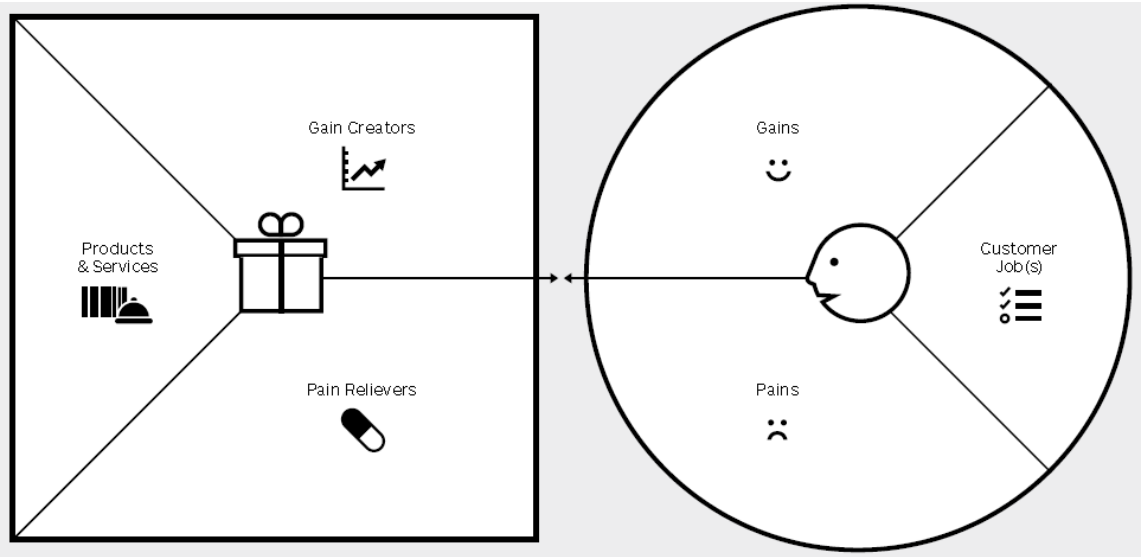
Data needs to be captured and stored during online workshops like physical workshops. Using a tool that offers the flexibility to work on a single document with multiple people simultaneously is advised, allowing everybody to contribute to the same document. The tool has to give the participants the ability to form blocks, lines and arrows in different shapes and sizes to make and fill different figures throughout the workshops.

8.3.2 Workshop 1 – Why?

Workshop 1 – Why? focusses on the motivation for creating an innovation strategy. By investigating and discussing the internal and external factors, trends, trigger points and other developments in the organisation's environment, the necessity to innovate is defined by the participants. For an overview of all the in- and outputs of the workshop see Figure 10 at the end of this sub chapter.

The first hour is concerned with getting the participants on the same page regarding the upcoming workshops. It starts with showing the participants an overview of the upcoming workshops. Discussing the overview gives the participants the last time to voice their opinion about the planning for the upcoming use of TRM. The next thing to establish is the scope, aim, and goal, to prevent pointless discussions during the workshops and manage false expectations.

The second hour is used to gather information about external motives to innovate. The decision was made to focus on the customers as Phaal and Muller (2009) states that it is important to keep the customer at the focal point of the innovation strategy. As for engineering consultancy firms holds satisfied customers ensure a continuation of business, therefore creating an innovation strategy that supports the customers is valuable.



Value map:	Customer profile:
- Gain creators: Which actions would create additional value for the customer? - Pain relievers: Which actions would prevent value from being taken from the customer? - Products & services: Which solutions are offered to the customer to help?	- Gains: Which events are experienced as positive by the customer? - Pains: Which events are experienced as negative by the customer? - Customer jobs: Which tasks does the customer require assistance?

Figure 9. An empty value proposition canvas.

Value proposition canvas (VPC) is a suitable tool to investigate the interaction with the customer and explore what adds value to the product or service they receive. The VPC helps the participants dissect their interaction with customers and capture customer wishes and needs, creating the desired awareness of the organisation's environment. The tool breaks down the problem for its users, making it an excellent tool for a someone less experienced in breaking down customer experiences. An alternative would be user stories. In a user story the needs of the end user are described. However, user stories are more abstract than VPC and their output less suitable for the sequel steps in the innovation strategy development process.

The VPC forces the participants to think about what they do for the customer and what the customer experiences as pleasant and unpleasant. In a VPC, the wants and needs of the customer are captured by answering six simple questions, as seen in the table in Figure 9. These wants and needs provided data for the innovation strategy. A VPC consists out of six areas, divided over two sides. The left side is the value map; the right side houses the customer profile. An empty value proposition canvas is shown in Figure 9. The participants should be divided into groups to complete the canvasses; the group size depends on the number of participants of the workshop and the number of customers the participants plan on treating in the VPC. Advised is assign two to three participants per canvas. The reason is twofold, 1) to involve all participants in an online workshop, large groups should be avoided. In this case, all participants working on the same canvas would result in two or three working and the rest not and 2) the workshop duration is not infinite, by splitting the group, more customers can be treated in VPC's.

The customers treated in the VPC are not actual customers. Although it is possible to treat individual customers, it is advised to create stereotype customers to save time. A stereotype customer presents a larger group of customers for which similar engineering consultant activities must be performed during projects. The number of stereotyped customers that can be treated during the workshop is depended on the group size and time available. In case of a larger group or more time, more distinctions between the customers can be made, creating more stereotype customers.

When trying to extract data for the innovation strategy from the VPC, the left side of the canvas will provide the most valuable data. This is because the left side contains actions, whereas the right side contains observations. The better an organisation does the actions on the left, the more satisfied the customer. These are thus the take-aways from this tool and are used in hour three of this workshop.

During hour three, the search for motivations to innovate is continued by examining what the innovation strategy should bring the participants themselves. The VPC should be used again as participants fill the VCP with themselves as customers from their innovation strategy. This VPC will be about changes the participants would like to make to their work activities. Like the VPC for the customer, when more time or workshop participants are available, more VPC with different job descriptions can be made. Again, as with the VPC for the customers, the most interesting side of the VPC is the left side of the canvas. The items on the left will serve as motives and reasons *why* certain products or services need to be developed, thus *why* there is a need to innovate.

In the last hour, so-called *innovation drivers* are formed. The participants have to group all the trends, events, and trigger points that come up on the VPC into innovation drivers. The grouping is done based on topics found in the VPC.

During the second half of the last hour, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is done with the innovation drivers. The SWOT analysis allows the participants to categorise the innovation drivers to determine how they will be dealt with in the innovation strategy. Table 6 shows the SWOT grid; each innovation driver is placed in one of the four squares of the grid.

Table 6. SWOT grid used in a SWOT analysis.

Strengths. Internal factors that are in the organisation's control and help the organisation reach its goals.	Weaknesses. Internal factors in the organisation's control but are preventing the organisation from reaching its goals.
Opportunities. External factors that can be developed to benefit the organisation.	Threats. External factors that are out of the organisation's control and potentially prevent the organisation from reaching its goals.

To prioritise the innovation drivers, a dot voting session is performed. The prioritised innovation drivers will help during the grid analysis of workshop 2 – What?. A dot voting session is an easy and effective tool to prioritise items with a large group. Each participant is allowed to hand out three dots. The three dots could be placed on the innovation drivers on the SWOT grid. Participants can put multiple dots on the same theme, prioritising the theme. The theme with the most dots has the highest priority to the team.

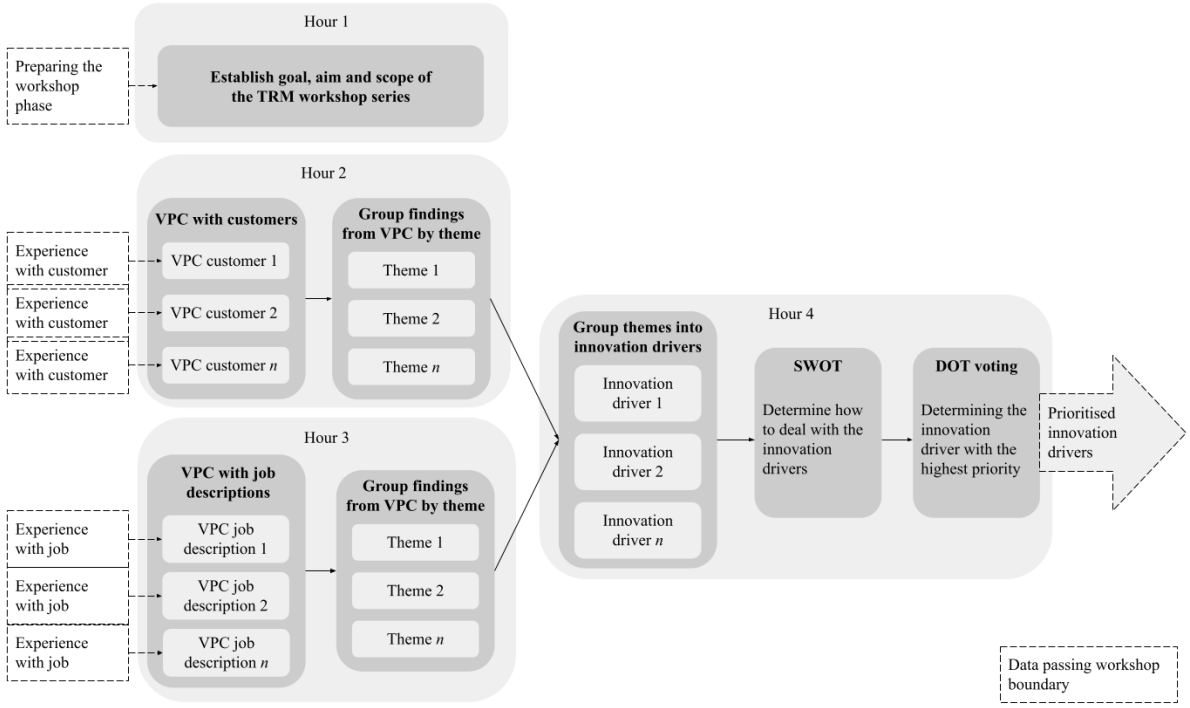


Figure 10. In- and output workshop one - Why?, see Appendix C for a full-page picture.

- After workshop 1 – Why? the participants have established a scope, aim, and goal for the workshop series. They also have developed a clear picture of the environment and market needs they will encounter in the upcoming years, along with what they desire from their innovation strategy.

8.3.3 Workshop 2 – What?

In workshop 2 – What? participants have to start making their vision about the future more concrete. The participants have to brainstorm about products, services, and capabilities to fulfil the innovation drivers from workshop one. These innovation driver fulfillers are called the *innovation elements*. For an overview of all the in- and outputs of the workshop, see Figure 11 at the end of this sub chapter.

Hour one starts with a recap of the previous workshop; this refreshes the participants' memory, bringing back what happened during workshop 1 – Why?. After the introduction, according to the TRM workshop plan from Table 5, the participants have to develop service features concepts. The features are developed via brainstorming about engineering consultancy and how they saw it develop in the upcoming years. The participants are asked to individually draw a mind map of what they thought their function would be like in ten years. Mind mapping is done by writing down words by association in a spiderweb or tree-like shape. Mind mapping is an appropriate tool as it is easy to understand and very flexible, preventing the participants from being hindered by the tool in expressing their thoughts. During the second hour, the mind mapping is continued.

Hour three starts with the creation of the innovation elements. The participants are asked to look for themes in their mind maps; this can be done by labelling the words in the mind maps. The themes from all the mind maps are again grouped by theme like in the first workshop, creating the innovation elements.

The innovation elements must be checked against the scope in preparation for the grid analysis. The participants have total freedom to create their mind maps. This means when the topics from all the mind maps are brought together into the innovation element, some of these elements lay outside of the scope of the innovation strategy. For that reason, these elements are from then on left out of the process. The grid analysis was described in chapter 5.5 Designed TRM method: The workshops on page 20.

In the grid analysis, the innovation drivers from the first workshop are put in a grid with the innovation elements. Each participant has their own grid, each time an innovation element fulfils an innovation driver, a mark is placed in the grid by the participant. In the end, the innovation element

with the most marks has the highest priority as it will have the most significant impact when developed. The online version of Microsoft Excel or Google Sheets can be used to create a file in which each participant has their own sheet to perform the grid analysis. Then, through the formulas in Excel or Sheets, all the grid analyses from the participants can be combined to form an overview grid which will show the prioritised innovation elements.

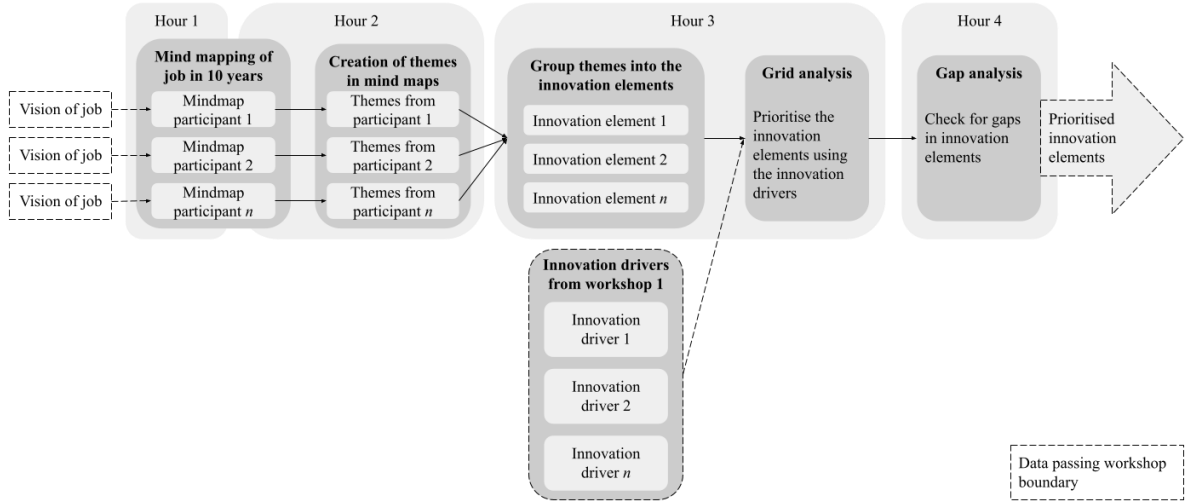


Figure 11. In- and output workshop two - What?, see Appendix C for a full-page picture.

- After workshop 2 – What? it should be clear how the innovation elements will fulfil the innovation drivers. The innovation elements are either products or services that can be offered to customers. In the next workshop, resources are allocated to develop the innovation elements.

8.3.4 Workshop 3 – How?

The goal of workshop 3 – How? is to find ways to execute the innovation elements from workshop 2 – What?. These solutions are called *resources*; a resource can be many things, it can be knowledge, partnerships, interns, technologies, financial means, etc. For an overview of all the in- and outputs of the workshop, see Figure 12 at the end of this sub chapter.

In teams of two, the participants have to brainstorm about the innovation elements formed in workshop two as these are still very abstract terms. The mind maps from the previous workshop might offer some more actionable implication of an innovation element as some of these innovation elements are still very abstract and need to be turned into actions before allocating them. For instance, if the innovation element would be wireless data transmission, a way to make it actionable would be Bluetooth.

Each innovation element has its own canvas, and participants will add sticky notes with possible ways to turn these abstract ideas into actions. Each canvas will be visited in groups of two until the participants feel like no contributions can be made to the innovation element anymore.

Once all the innovation elements have several possible actions that could lead to the execution of the innovation element, the participants have to brainstorm about the resources required to execute or perform the innovation elements. Examples of resources are interns, partnerships, money, time, and internal collaborations. It is advised to use a different colour sticky notes to keep track of the difference between innovation elements and resources. Finally, all the resources are grouped into themes, like the innovation drivers and elements, to create the sublayers in the how?-layer of the technology roadmap. A final grid analysis is performed to determine the resources most important to the innovation strategy. The final step is to do a gap analysis on the resources.

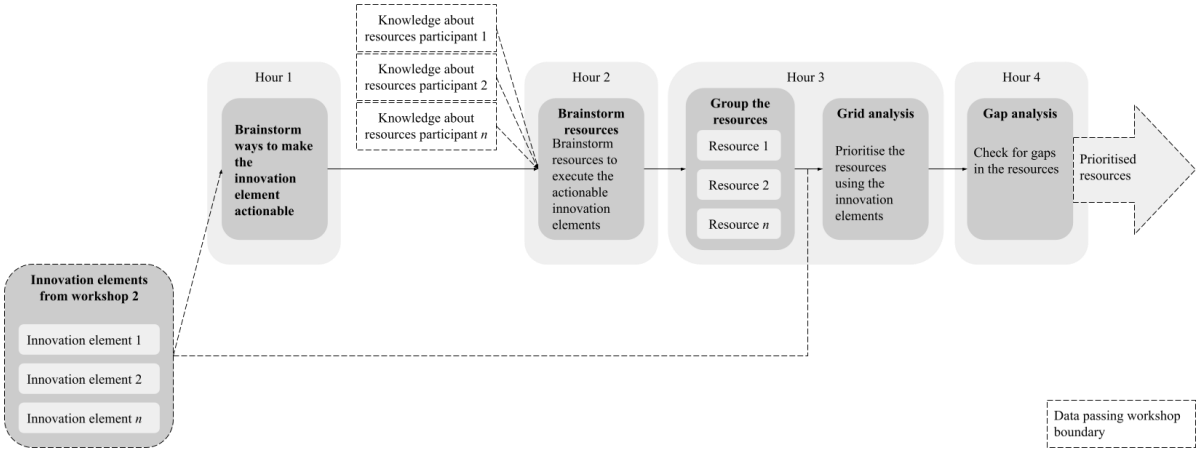


Figure 12. In- and output workshop three - How?, see Appendix C for a full-page picture.

- After workshop 3 – How? the participants should have a good idea of how they will achieve the desired innovation strategy. The resources are matched with the innovation elements and are ready to be put on a timeline during the last workshop.

8.3.5 Workshop 4 – When?

Workshop 4 – When? ties it all together through the creation of the technology roadmap. The technology roadmap can be made digital or on a large piece of paper with sticky notes. The latter is preferred as multiple participants can simultaneously create the technology roadmap. For an overview of all the in- and outputs of the workshop, see Figure 13 at the end of this sub chapter.

Hour one starts again by introducing the upcoming workshop and a recap of previous workshops. Verifying the goal, aim and scope one last time with the participants before the roadmapping starts is advised to ensure all participants are still on the same page. After which, the visualising of the technology roadmap begins. First, the architecture needs to be drawn on a large white sheet of paper. Let the participants do this themselves; this will strengthen the feeling that it is their roadmap, and the sense of ownership will later help with the implementation.

The first layer to be mapped out is the why?-layer. The first things that need to be defined are the sub-layers. The innovation drivers defined in workshop 1 – Why? are used to name the sub-layers of the why-layer. Next up, the sub-layers are filled with trigger points, trends, etc., also from workshop 1 – Why?. A colour scheme is advised as the technology roadmap becomes more organised, making it easier to connect the different layers near the end of this workshop. After each layer is completed, the participants should take the time to check if they all understand what is written down on the technology roadmap and if something is missing from the layer.

Hour two is about the what?-layer. Again, the participants have to start with filling in the sublayers. The sublayers are the innovation elements defined during workshop 2 – What?. Filling in the sublayers requires planning as not all products, services or capabilities can be developed simultaneously. The grid analysis done in workshop two can act as a guide here. The innovation elements that satisfy the innovation drivers with the highest priority should take precedence over lower priority innovation elements.

Hour three is dedicated to the lowest layer on the technology roadmap, the how?-layer. The themes of the grouped resources from workshop 3 – How? are taken as sub-layers. After the sub-layers are filled in, it is time to indicate the connections between the innovation elements and the resources. Drawing the lines across the layers of the technology roadmap visualises how the innovation drivers from the first workshop are composed of sub-products and services, the innovation elements and how the resources form these elements.

In the last hour of the workshop series, a final gap analysis is performed, and discussions about the future of the technology roadmap should be held. Discussing these gaps and how to get rid of them will help strengthen the innovation strategy.

Once the technology roadmap is finished, the future of the technology roadmap has to be discussed. The discussion is started by the moderator asking a series of questions to the participants. These questions make them aware that a change in their organisational culture is required for the designed

TRM method to be successful and stay successful in the future. Example of these questions are ‘Why the participants had not made such an innovation strategy by themselves?’, ‘Why their strategy towards innovation was going to change after the workshops had finished?’, and ‘How they were going to change their attitude toward innovation?’.

The following discussion that the moderator starts is about the practical matters regarding the technology roadmap; s/he should ask questions like ‘when and who would decide the technology roadmap needed updating?’, and ‘When will the technology roadmap be leading?’. This discussion marks the end of the last workshop.

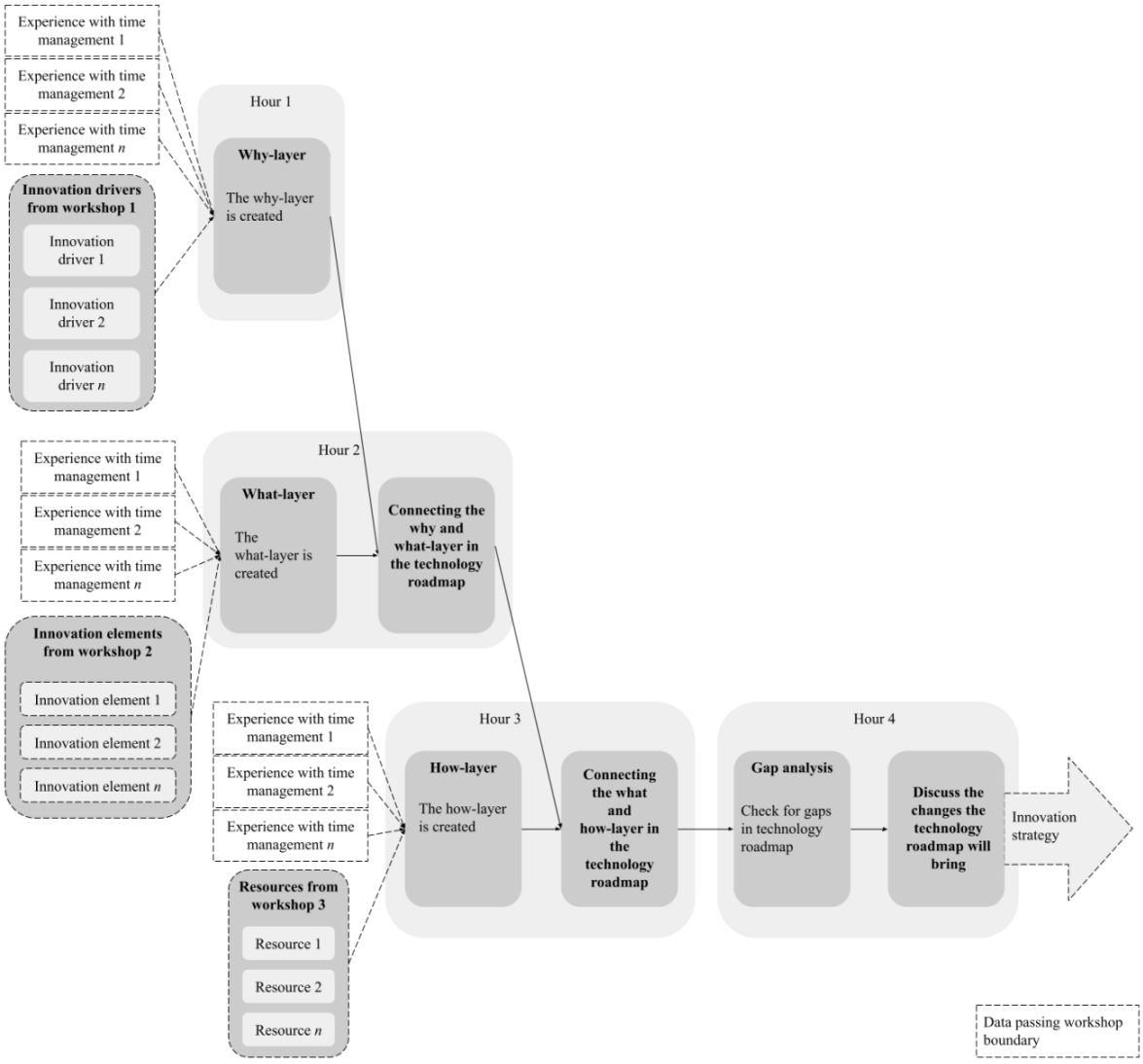


Figure 13. In- and output workshop four - When?, see Appendix C for a full-page picture.

- After the last workshop, workshop 4 – When?, the participants should have created a technology roadmap providing them with a planning for their innovation strategy. In the process of making the technology roadmap, the participants will have shared their vision and gave their input on the future and what they think is essential. Furthermore, by discussing the future steps the participants have to take, the newly created roadmap has a higher chance of being accepted and used by the participants.

8.4 The designed TRM method

In chapter 8, the designed TRM method is presented. To the preparing the workshops and workshop phase, more operational details were added. Table 7 shows an overview of the workshops and their content on an hourly basis.

Table 7. Workshop planning of the designed TRM method.

	Workshop 1 – Why?	**Workshop 2 – What?**	**Workshop 3 – How?**	**Workshop 4 – When?**
Hour 1	• Introduction • Establishing the scope, aim, and goal.	• Introduction and recap of the previous workshop. • Mind map about the future of engineering consultancy by mind mapping.	• Introduction and recap of previous workshops. • Brainstorming possible resources.	• Introduction and recap of previous workshops. • Roadmapping, why?-layer
Hour 2	• VPC with the customer.	• Mind map about the future of engineering consultancy by mind mapping *continued.*	• Brainstorming possible resources *continued.*	• Roadmapping, what?-layer. • Connecting the why? and what?-layer.
Hour 3	• VPC with the specialist group as customer of their innovation strategy.	• Creation of innovation elements. • Prioritising via grid analysis.	• Grouping the resources. • Prioritising via grid analysis.	• Roadmapping, how?-layer. • Connecting the what? and how?-layer.
Hour 4	• Creation of innovation drivers. • SWOT analysis • Prioritising via DOT voting.	• Gap analysis	• Gap analysis	• Gap analysis • Discussing the implementing of the technology roadmap.

9 Design cycle two: validation through TAR of designed TRM method

To validate the designed TRM method for engineering consultancy firms to develop their innovation strategy, TAR was used. With TAR, the designed TRM method was implemented in the real world by the researcher to investigate if the application of the designed TRM method indeed treats the problem. The client was the specialist group 'transmission pipelines' at Sweco, who developed their innovation strategy with the designed TRM method.

This chapter will proceed as follows; first, a case description is given of implementing the designed TRM method in the specialist group. Next, this implementation was evaluated through interviews with three of the participants. After which, the designed TRM method is validated by the researcher.

9.1 The implementation of the designed TRM method in specialist group 'transmission pipelines' at Sweco

The designed TRM method was applied in the consultancy engineering firm Sweco. A specialist group at Sweco needed an innovation strategy. The specialist group was specialised in transmission pipelines and consisted out of seven people. The specialist group has people performing advisory work and transmission pipeline designs, i.e., plotting the pipelines underground. At Sweco, the specialist groups themselves determine which market they want to target with their specialist knowledge and how they plan on targeting that market. There were no individuals dedicated to research and development, any exploration of innovations happened during projects for customers.

9.1.1 Preparing the workshops with the specialist group

The process started with the researcher introducing TRM in the team, described in subchapter 8.2 Designed TRM method: the preparing the workshops phase. Since the one- and five-year plan from the specialist group already expressed a sense of urgency regarding digital innovation, there was no need to raise additional awareness. Instead, they knew that they would benefit from an innovation strategy that would help them plan innovation exploration.

The specialist group leader was the owner of the business problem, as within Sweco, he is responsible for the performance of the specialist group. The researcher met with the business problem owner and two other senior members of the specialist group and determined a first draft of the scope, goal and aim. The scope was said to be 'the development of an innovation strategy for the team'. The goal was 'to draft a first version of the technology roadmap through TRM'. The aim was 'to create a plan of the innovation strategy which would suit everybody within the team and give the team a direction for the future'. The TRM workshops were allowed to take four times half a day, and everybody in the team had to participate. The level of detail should be such that every team member should understand the things written down on the technology roadmap.

Educating a TRM expert was a commitment the specialist group were not ready to make. The specialist group leader wanted to try the method first before committing the resources to make a person in their team an expert. No TRM expert on the team meant reserving more time in the workshop to explain the different activities in the workshops. The researcher would also have to be extra cautious that the participants would not wander off into a direction that would not contribute to the innovation strategy as he was the only one capable of guarding the quality of the output. The first draft of the scope, goal and aim of the workshop, which was drafted up early with the leader of the specialist group and two other members, were discussed with the entire specialist group as described by the designed TRM method in a pre-workshop meeting.

The TRM workshop plan presented in Table 7 was used without modification as the specialist group agreed with four workshops of half a day each. There was approximately one week between each of the workshops. The last workshop was hosted physically with all the participants due to relaxed COVID-19 restrictions.

9.1.2 Online workshops

During three of the four workshops, the web-based video tool 'Spacial chat' was used to host the workshops online. In this tool, each participant is represented as a circle containing the video feeds from their webcam. Spacial chat allowed the participants to move freely around in a 2D environment. Depending on the distance participants have from one another in the online environment, the audio of a person is muted. The distance-based audio volume allowed participants to form groups themselves

and the researcher to wander around the different groups. Although not the same as a large room with different tables, it did suffice for the workshops.

The web-based tool ‘Mural’ was used to capture and store the knowledge. Mural is an online version of a large whiteboard. All the participants joined a single Mural which was prepared by the researcher depending on the workshop.

9.1.3 Workshop 1 – Why?

The first VPC was filled with stereotyped customers. The specialist group chose two stereotyped customers; one for which ‘consultancy/data’ work had to be performed, and the other was for ‘design’ customers. A consultancy/data customer required the expertise or solution to a transmission pipeline problem, i.e. hydraulic calculations or the organisation of complex projects. A design customer required a 2 or 3D drawing of a transmission pipeline network.

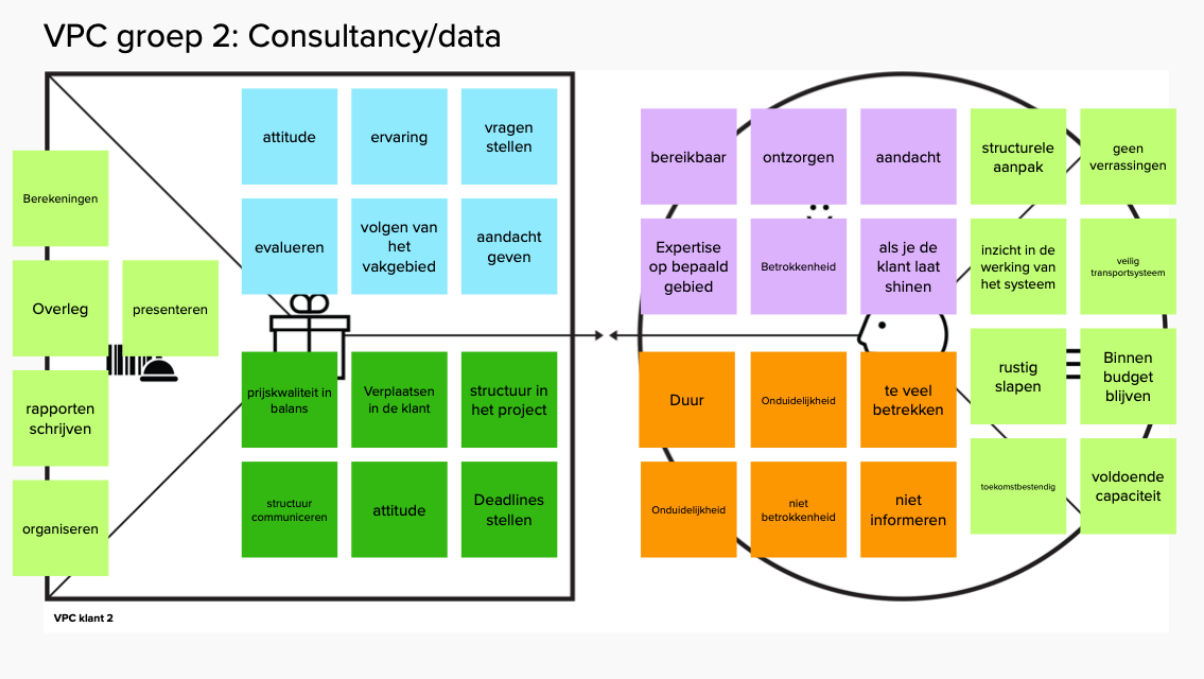


Figure 14. Value proposition canvas for customers from the consultancy/data customer.

The VPC for the consultancy/data customers in Figure 14 shows external motives why the specialist group should innovate. For instance, ‘price/quality balance’ is a reason why they want to innovate. If the specialist group were to innovate a service that would lead to a better ‘price/quality balance’, the customer would be pleased as it would release pain and thus create value in the eyes of the customer.

The next would be the VPC that investigated internal motives to innovate. The specialist group was again divided into two groups; the first group consisted of ‘consultants’, and the second group filled out the canvas as ‘designers’. Figure 15 shows the canvas made by the designers. The distinction between designers and consultants was made because the designers' requirements of the innovation strategy are different from the consultants as the designers' work is more dependent on the latest technologies such as virtual reality, 3D design software, and AI solutions.

Figure 16 shows the next step; the formation of innovation drivers. The sticky notes from all the VPC were copied on an empty Mural and grouped per topic; each topic would be called an innovation driver.

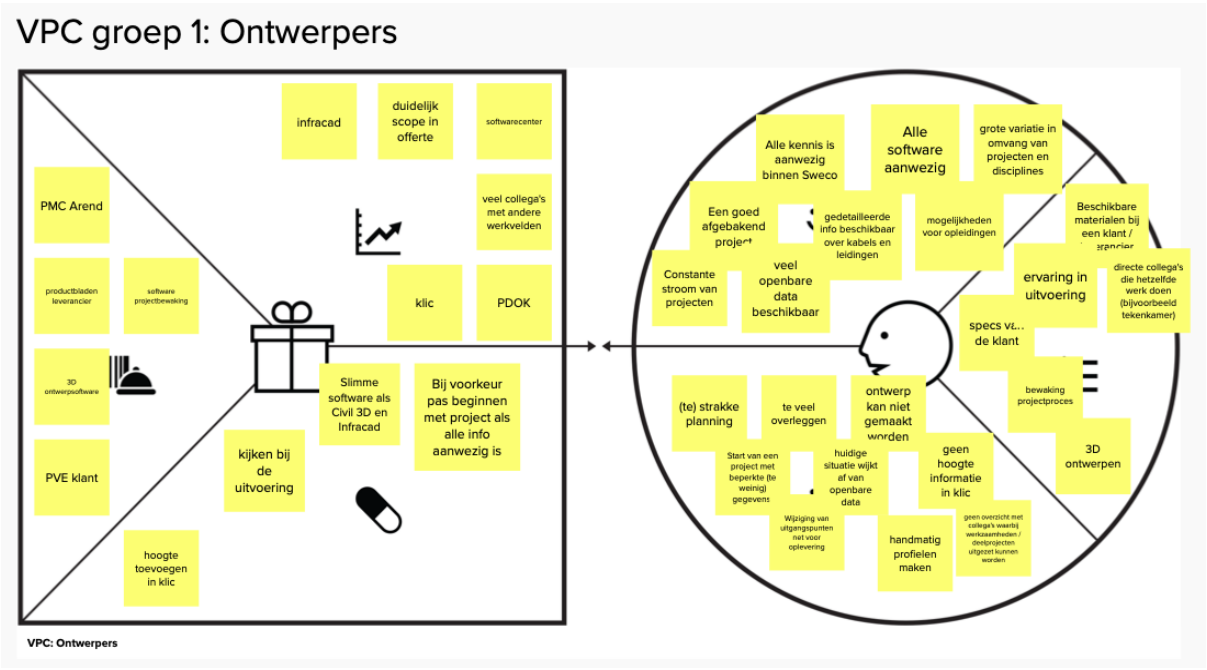


Figure 15. Value proposition canvas made by the 'designers'.

Once the innovation drivers were known, the SWOT analysis was performed. Some examples of innovation drivers and reasoning behind their placement in the SWOT grid were: Open communication as a strength as the participants felt they had complete control over their communication style. Collaborations as an opportunity as they felt like they were not doing enough collaborations with external parties like knowledge institutions. Furthermore, software was perceived as a weakness, something they felt they had to improve and was entirely in their control.

During the dot voting session, where the participants had the rank the innovation drivers in the SWOT grid to their importance, open communication and collaboration both scored two dots, whereas software scored one dot. The higher score for open communication and collaboration was a remarkable result as there was much to gain in software development and use. In contrast, open communication and collaboration were already present at a high level in the specialist group. The scores given during the dot voting session were used during the next workshop to calculate the importance of the innovation elements.

Throughout the first workshop, the participants were enthusiastic and stayed motived, despite the workshop being online and taking four hours. The first workshop was the most abstract; this required extra explanation as some tools, like VPC and SWOT, were new to the specialist group members. Despite the researcher's best efforts, the requested output was not always clear for all the participants.

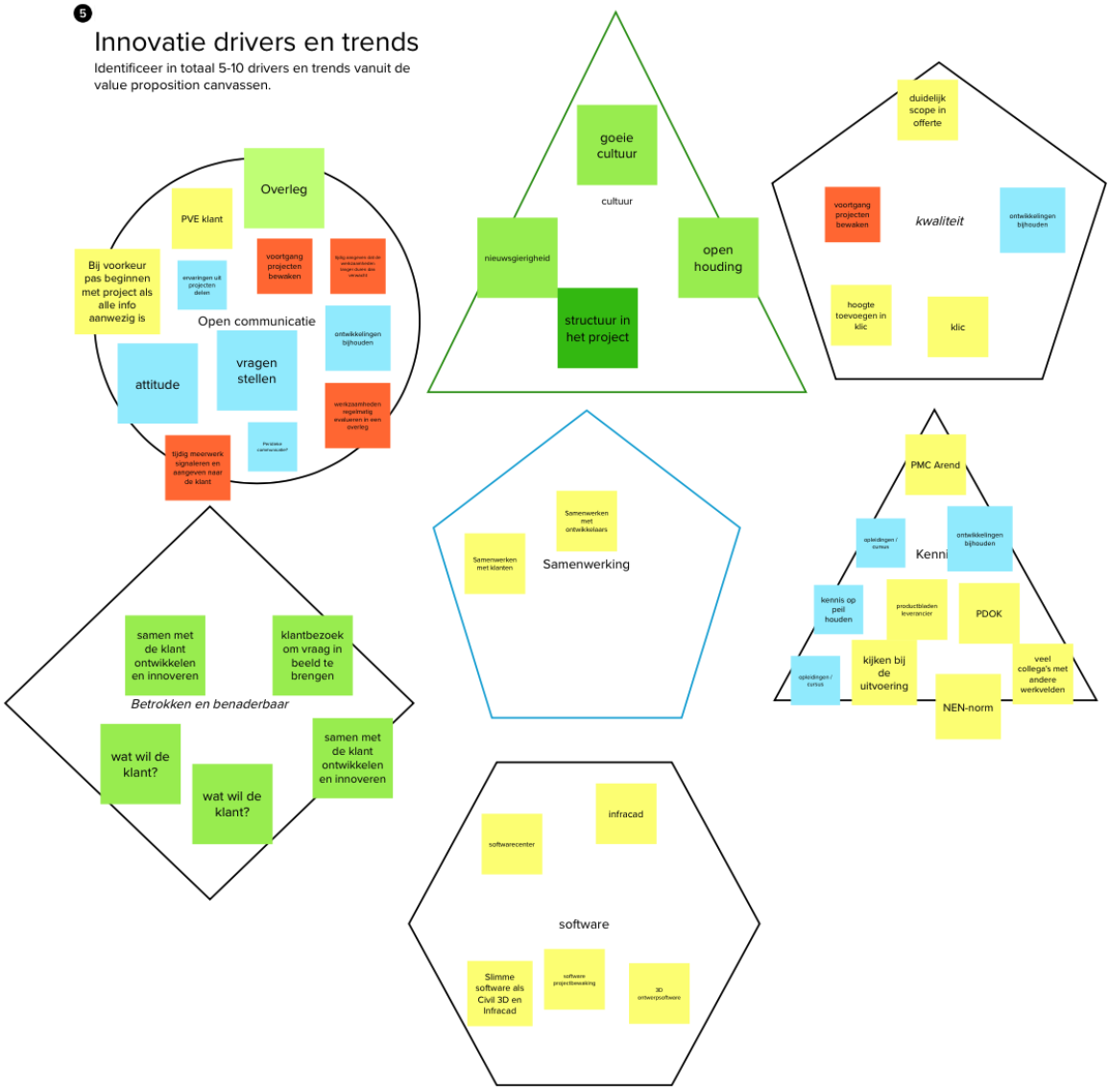


Figure 16. Grouping of the individual topics into the innovation drivers.

9.1.4 Workshop 2 – What?

During the second workshop, the specialist group members had to make a mind map that would describe their job in ten years. This resulted in seven mind maps with a prediction of what the future would hold for the engineering consultancy in the transmission pipeline sector, one of the mind maps is presented in Figure 17. The specialist group member responsible for the mind map in Figure 17 was a designer, and he had the vision that his work should look like a computer game. By computer game he meant an extensive computer model that would automate many steps he had to perform to deliver a satisfying result for the customer. Something that he noted was communication. He had a vision describing a centralised platform where he and others from Sweco would use to share and communicate work with clients or partnering organisations.

Figure 17. Mind map created during workshop two.

Once all the mind maps were complete, themes needed to be formed again. This was done by labelling all the mind map entries with sticky notes. The participant who made the mind map in Figure 17 used a colour scheme for the different themes. Next, all the sticky notes from the mind maps were combined on a single mural, and seven themes were formed in a similar way as Figure 16. These themes were called the innovation elements and would form the sub-layers during the fourth workshop. Examples of innovation elements were ‘data accessibility’, ‘uniform communication’ and ‘automatisation’. From the seven, two were not used in the following steps because these themes lay outside the scope and were not of interest to the innovation strategy.

Each participant had its own grid with the innovation drivers and elements in an online version of Microsoft Excel to rank the innovation elements. The first sheet in Excel combined all the specialist group members' grids, creating the overview. Data accessibility was voted most important as it would satisfy the most and most important innovation drivers.

To the researcher's surprise, the second workshop was the most difficult one to host. A few participants had some trouble creating a coherent mind map and were creating more associated topics. Also, two participants created the technology roadmap together as they were both working in the office that day, so they decided to sit together during the workshop.

9.1.5 Workshop 3 – How?

This workshop was experienced as pleasant by the specialist group members as plans for their innovation strategy got more concrete. They brainstormed about turning the innovations elements into actions that would result in the innovation elements described in the second workshop. Unfortunately, this third workshop was cut one hour short due to the last minute time constraints of the participants. Losing the last hour left no time for the grouping of resources by the participants. The researcher grouped the resources afterwards and confirmed his work at the beginning of the fourth workshop with the specialist group members.

9.1.6 Workshop 4 – When?

The last workshop was hosted physically. Of all the workshops in the designed TRM method, this workshop benefitted the most from the physical environment as participants can easily communicate and discuss topics with the group. The workshop took place in a large room with a large table in the

middle. A screen to present was used to recap the previous workshops, and the researcher presented the agenda for this last workshop.

A large piece of paper and sticky notes were used during the case. Each layer was filled with sticky notes with the outcomes from the previous workshops. During this process, numerous discussions were held, varying in length. Only when the participants were completely off-topic were the participants reminded by the researcher that time was limited and if the discussion they were having was of actual value to the creation of the technology roadmap.

Figure 18. First draft of the technology roadmap drafted by the specialist group at Sweco.

During this last workshop, the specialist group members had some difficulty considering the time aspect; this can be seen by some arrows pointing left and up from a lower layer to a higher one. Arrows pointing left and up would mean the product was developed before the R&D had happened. Luckily, there was at least some sequencing done among the sticky notes, but the timeline drawn above was not kept as nicely as planned.

The technology roadmap created in the final workshop is only a first draft, and some imperfections are to be expected. For example, another operational detail that did not go according to the designed TRM method was using a colour scheme in the stick notes. The specialist group members thought it would be too complicated and abandoned that idea. The same held for the sticky note shaped like a star. This sticky note was also used as a regular, square sticky note and bared no special meaning.

The technology roadmap in Figure 18 visualised the gaps in the innovation strategy of the specialist group, as there were actual gaps, places with no sticky notes, where there was either no resources or there was no product, service or capability being developed, or there was no knowledge/vision for the future. In future versions of the technology roadmap, these gaps can be resolved by acquiring knowledge and inspiration to fill the gaps.

During the final discussion regarding the future of the technology roadmap, the specialist group decided to digitise the technology roadmap as the one produced in the final workshop was only a first draft and needed to be tidied up. There was no date planned to update the technology roadmap as the specialist group first wanted to see the effect of the technology roadmap created that day.

To implement the created innovation strategy in ongoing business, the specialist group used Scrum. While not part of the designed TRM method, the specialist group was introduced to an Agile way of working via the Scrum tool earlier that year. The specialist group used the Scrum tool to execute the actions resulting from the technology roadmap.

Pictures were taken of the paper roadmap and stored for later use. The participants quickly reviewed the method and the necessity of the three workshops leading up to this final one. They concluded that the three workshops prior to the last one were helpful as they realised that the only thing they did in the last workshop was to write down the resources, innovation drivers and elements on sticky notes and place them on the technology roadmap. So, they would have run out of time if they had tried coming up with the innovation drivers and elements in the one workshop.

The last workshop was physical; this was experienced as most pleasant by the participants. Communication was easier as non-verbal communication was less difficult to interpret, and discussions could be held with the entire group. The group discussions fortified the feeling of being part of a group. Also, the role of the researcher was less prominent as after instructions, the participants were better able to figure out what to do and could help each other when they had questions.

9.2 Implementation evaluation of the designed TRM method

To determine the success of the designed TRM method at the specialist group, three members of the specialist group were interviewed. The interview contained five questions regarding the designed TRM method. Through these five questions, the implementation of the designed TRM method was evaluated.

1. Did the designed TRM method facilitate the discussion about the impact of external influences and the organisation's environment on the innovation strategy?

Interviewee one talked about how the designed TRM method did facilitate the discussion by having the participants take a step back in the first workshop and look at the bigger picture: *"Technical people, but maybe also other types of people tend to search directly for solutions and want to take action. But [with the designed TRM method] you first have to analyse why? And what is required?"* When the participants asked themselves these questions, it forced them to connect the specialist group with the rest of the world, thus discussing the impact of external influences and the environment on the innovation strategy.

Interviewees two and three agreed with interviewee one, as an example interviewee three talked about how she was forced to consider the whole picture: *"As you do not immediately have to think of feasible ideas or products or something where we need to be heading to, but first have to consider the things around us, the external factors, to which we are going to adapt our work to."* Based on this, the conclusion about evaluation criterion one is that the designed TRM method facilitated the discussion about the impact of external influences and the organisation's environment on the innovation strategy.

2. Did the designed TRM method facilitate the discussion about the impact of internal firm developments on the innovation strategy?

Interviewee one agreed. Interviewee two expressed that the designed TRM method did indeed facilitate the discussion about a place for internal development in the innovation strategy: *"For the things [developments and changes in the way the specialist group worked] we wanted, there was space."* Furthermore, he gave the following example of ongoing internal development: *"We got things like BIM [Building Information Model], we are working on that for quite a while, and we have added that [to the technology roadmap]."*

Interviewee three on the designed TRM method facilitating the discussion about the impact of internal firm developments: *"These are activities on which we are currently working, and these came at the beginning of the technology roadmap, all the way on the left. […] I have the feeling that those activities all have got a clear role or place on the technology roadmap that we have made."* The interviewees both pointed out where the internal firm developments were placed on the technology roadmap, meaning that the designed TRM method did facilitate a discussion about the impact of internal developments on the innovation strategy. Based on this, the conclusion about evaluation criterion two is that the designed TRM method did facilitate the discussion about the impact of internal firm developments on the innovation strategy.

3. Did the designed TRM method facilitate the discussion on planning the innovation strategy?

All interviewees agreed that the designed TRM method did facilitate a discussion about the planning, as interviewee one talked about the planning aspect of the designed TRM method: *"Yes, I do think we paid attention to it [placement of sticky notes in a time-sensitive manner]. We placed the sticky notes quite deliberately on those long bands [the layers on the technology roadmap]. I do think we might have gone over it a bit too fast. Maybe that should have been the work planning, and maybe we should*

have had this moment where everybody agreed with each other on this is how we are going to move forward."

The interviewees also all agreed planning was the most challenging part, as interviewee three explained the struggle she experienced planning: *"Yes, I found that the most difficult part. One thinks in the moment; what is currently happening around us? How can we utilise it?"*

Based on this, the conclusion about evaluation criterium three is that the designed TRM method did facilitate the discussion on planning the innovation strategy.

4. Did the designed TRM method facilitate the formation of a roadmap that captures and visualises the information gathered during the workshops?

Interviewee one was positive about the designed TRM methods ability to extract information from all of the participants: *"Yes, I think it [the capturing of knowledge] went all right. Yes, there was a really peaceful atmosphere, everybody got plenty of time. We could all say what we wanted to say, and I think the last session was the best. […] it did make a difference in this case whether it was online or physical."* This quote from interviewee one indicates that he experienced the workshops as a safe environment for everybody to have time to think and speak their minds. As it was a safe environment, no knowledge was left out due to participants not being able to speak up, and thus, knowledge loss was minimised by the designed TRM method.

The online workshops created benefits for those participants that usually are less outspoken, and interviewee three said: *"I think it [the methods used in the online workshops] helped everyone to speak their minds. Especially during the [online] workshops, as you got some time by yourself to think things over. If you are in a team or a meeting without a clear plan behind the meeting, the same people will often speak. With the different workshop techniques, everybody could say something and as a result, we got ideas from all of the team members. I think this would not have happened otherwise."*

Interviewees two and three both mentioned they were positive regarding the visualisation techniques used; interviewee three: *"In the last session, everything suddenly was visualised. Before it was all there, but we were like, 'Where do we find everything? Where is it?' Bringing it all together on a poster, I think, is important."* Based on this, the conclusion about evaluation criterion four is that the designed TRM method did facilitate the formation of a roadmap that captures and visualises the information gathered during the workshops.

5. Did the designed TRM method facilitate the team members internal communication and alignment?

Interviewee two thought it helped with the alignment of the participants: *"I think it [technology roadmapping workshops] helped us."* He explains: *"In the back of our minds, we had a lot of things we wanted to do. Only now we have made them more concrete, things like energy transition, climate adaptation, you name it. It was also good that we had discussions with the entire specialist group. […] That is the beauty of this method, everyone is part of the process, and that makes everybody involved with the future developments of the process and the task that come with it."* Having the entire specialist group involved in the discussion helped with the alignment of the team as everyone could participate and experience the workshops first-hand.

Interviewee three had a similar opinion regarding the designed TRM method creating discussion; she adds: *"[…] and that it [the technology roadmap] is not something from the specialist group leader who came up with something to which you can only answer 'yes' or 'no'. You, yourself and everybody is now also responsible for the specialist group and where we are heading. And if you say nothing, then your part will not end up in the technology roadmap. So, everybody has an equal ownership of the specialist group, and it is together that we are going to do something."* Making all the participants responsible for creating the innovation strategy forced them to actively participate in the workshops, creating discussion and improving communication and alignment within the team.

Interviewee one emphasises that the structure the designed TRM method created helps create a bond between the employees: *"I think that if you structure, with your colleges or a company, a chosen path, that the people have something to hold on to while they work. That is a big, big advantage, the structure."* Based on this, the conclusion about evaluation criterion five is that the designed TRM method did facilitate the improvement of the team members internal communication and alignment.

Since all the five evaluation criteria were satisfied according to all of the interviewees, the implementation of the designed TRM method was considered successful.

9.3 Validation of the designed TRM method

During validation in TAR, the requirements from chapter 5.1 Requirements for the designed TRM method and 8.1 Additional requirements for the designed TRM method were validated by investigating whether the designed TRM method satisfied the requirements during the implementation of the designed TRM method. Each of the nine requirement is discussed below.

Requirement one: *The designed TRM method had to use or partially use qualitative data to develop the innovation strategy.* The specialist group members used the prescribed tools by the designed TRM method, VPC, SWOT and DOT voting in the first workshop, as seen in chapter 9.1.3 Workshop 1 – Why? and mind mapping in the second workshop described in chapter 9.1.4 Workshop 2 – What?. These tools needed qualitative data as input, satisfying the first requirement.

Requirement two: *The designed TRM method has to use some form of expert-based data processing.* The specialist group members, experts in their field of engineering, discussed the data before using it in various tools, or the data was discussed after the new insights were gained through the various tools in all of the workshops. As the specialist group members did not deviate from the designed TRM method, the second requirement was satisfied.

Requirement three: *The designed TRM method requires the product 'the technology roadmap' that follows from the method to be made by the workshop participants.* The specialist group followed the fourth workshop as intended, and brought together the first three workshops and constructed their technology roadmap as described in chapter 9.1.6 Workshop 4 – When?, it thus was concluded that the third requirement was also satisfied.

Requirement four: *The designed TRM method should facilitate the discussion about the impact of external influences and the organisation's environment on the innovation strategy.* The VPC made the specialist group members think and discuss the customers and their impact on the innovation strategy. For example, interviewee three said how during the first workshop, described in chapter 9.1.3 Workshop 1 – Why?, the designed TRM method made her aware of changes surrounding the specialist group: *"As you don't immediately have to think of feasible ideas or products or something where we need to be heading to, but first have to consider the things around us, the external factors, to which we are going to adapt our work to."* The discussion held during the use of the VPC satisfied the fourth requirement.

Requirement five: *The designed TRM method should facilitate the discussion about the impact of internal firm developments on the innovation strategy.* The VPC in the first workshop described in chapter 9.1.3 Workshop 1 – Why? helped the specialist group members to consider what they experienced as pleasant during the execution of their jobs. The mind map in the second workshop described in chapter 9.1.4 Workshop 2 – What? let the specialist group members step for step, visualise their vision of the future of their job activities. With both these tools as part of the designed TRM method, the designed TRM method facilitated the discussion about the impact of internal firm developments on the innovation strategy, satisfying the fifth requirement.

Requirement six: *The designed TRM method should facilitate the discussion on planning the innovation strategy.* The fourth workshop was executed as prescribed by the designed TRM method: the fourth workshop made the specialist group add the time component to their innovation element, drivers and resources, making them plan their innovation strategy, as described in chapter 9.1.6 Workshop 4 – When?. Therefore, the fourth workshop satisfies the sixth requirement.

Requirement seven: *The designed TRM method should facilitate the team members internal communication and alignment.* As stated by interviewees two and three, using the designed TRM method made each specialist group member communicate their ideas and contribute to the innovation strategy. Together they had to form a new plan for the specialist group's innovation strategy. During the interview, interviewee two said the following about the alignment between the participants: *"I think it [technology roadmapping workshops] helped us."* He explains: *"In the back of our minds we had a lot of things we wanted to do. Only now we have made them more concrete, things like energy transition, climate adaptation, you name it. It was also good that we had discussions with the entire specialist group. […] That is the beauty of this method, everyone is part of the process, and that makes everybody involved with the future developments of the process and the task that come with it."* Based on the interviews and the observations, the seventh requirement was also satisfied.

Requirement eight: *The designed TRM method should prescribe what needs to happen during the workshop on an hourly basis.* The specialist group used and followed the designed TRM method described in chapter 8.4 The designed TRM method. Table 7 describes on an hourly basis what needed to happen during the designed TRM methods workshops to develop an engineering consultancy's innovation strategy, satisfying the eighth requirement.

Requirement nine: *The designed TRM method should specify the tools used to guide the discussions.* The designed TRM method specified the tools the specialist group members had to use in the various workshops. During the implementation, no new or other tools needed to be added to the TRM workshops to develop the technology roadmap, satisfying the ninth requirement.

Through the interview and the case description, it was concluded that the implementation of the designed TRM method was a success, and the case was used to validate the designed TRM method.

The validation was completed with success as to all the requirements set in chapter 5.1 Requirements for the designed TRM method and 8.1 Additional requirements for the designed TRM method proof as to why they were satisfied by the designed TRM method was found.

10 Discussion

This section starts with the discussion of the theoretical and practical implications of the results. Next, the limitations and advice for future research are given. Finally, the chapter will finish with practical recommendations for organisations wanting to use the designed TRM method.

10.1 Theoretical implications

The first theoretical implication of this study was the expansion of the TRM literature with a TRM method designed for the engineering consultancy firms to develop their innovation strategy. The designed TRM method is based on the T-plan by Phaal. Phaal describes a wide variety of T-plan applications of TRM in product-oriented organisation (Kerr & Phaal, 2015; Phaal et al., 2001, 2004a; Phaal et al., 2013; Phaal et al., 2004b; Phaal & Muller, 2009; Phaal et al., 2008). Wells et al. (2004) already used a T-plan based TRM in a service-oriented organisation, i.e. the United Kingdom Royal Mail. The performed research builds onto the work of Phaal et al. (2013) and Wells et al. (2004) by adding a new service-oriented sector, the engineering consultancy. The engineering consultancy is a novel addition to the T-plan based TRM literature as engineering consultancy is a different than any application TRM is ever used for previous to this study. The large variety of unique problem contexts engineering consultancy has to deal with and the project-based way of delivering tailored advice to the customers is not like the continues process the postal services had to develop (Wells et al., 2004). This makes the designed TRM method for engineering consultancy firms and the implementation of the TRM method described in a case novel contributions to the TRM literature.

Since the designed TRM method lets the participants start the development of the innovation strategy without any preconceived notion of what they want to achieve or where they want to end up with their innovation strategy, the first two workshops of designed TRM method contribute to the S-plan by Phaal (2007). The S-plan is designed to explore organisation surroundings for opportunities and subsequently select a direction to develop a strategy. The designed TRM method lets users explore different directions the innovation strategy could be heading during the first and second workshops. The designed TRM method provides the S-plan literature with an example of a workshop planning that lets the users explore innovation opportunities in the organisation's surroundings.

The designed TRM method also adds an example of a TRM method that transitions from S-plan activities to the T-plan. The participants go from a blank piece of paper, the starting point of the S-plan activities, to the end product of the T-plan, a technology roadmap of their innovation strategy. Therefore, the designed TRM method lets the participants of the TRM workshops not only explore directions for strategies, they also carefully transition from exploring directions to developing a strategy.

10.2 Practical implications

This study designed a TRM method with the ability to let a group of experts on an engineering topic develop an innovation strategy without any prior knowledge of innovation strategies or how to develop them. The designed TRM method guides the group of experts from the exploratory phase to a detailed technology roadmap containing the innovation strategy. Additionally, the designed TRM method supports the experts in documenting the innovation strategy. No other method is able to provide such a complete innovation development process to let a group of experts with little or no experience of innovation strategies develop an innovation strategy. Method like Delphi or scenario planning are only focussed on developing a description of the future, little attention is given to develop strategies to benefit from the created scenarios. On top of that, the methods are limited by its user’s ability to create a complete mental model of the future right from scratch. In case of Delphi to fill in a questionnaire or in scenario planning its users need to come up with multiple mini scenarios to compare to each other. Whereas with the designed TRM method, the vision is gradually built up through VPC, SWOT, and DOT voting and only in the last workshop the experts are asked to form a single description of the future.

Next to designing the TRM method, this study also validated the designed TRM method by implementing it at Sweco, an engineering consultancy firm. A specialist group within Sweco used the designed TRM method to develop their innovation strategy. The case study description, evaluation and the validation are proof of the functioning of the designed TRM method. The specialist group was enthusiastic about the designed TRM method as confirmed in the evaluation interviews. All the three

interviewees confirmed the designed TRM method worked as intended as they ended up with a technology roadmap that served as their innovation strategy. Interestingly, the participants experienced the workshops as empowering as they described how they felt like it was their innovation strategy, they were responsible for the content of the innovation strategy and all participants had an equal weight in prioritising innovation drivers, elements or resources.

Besides the technology roadmap, the specialist group got other benefits from the designed TRM method. In interviews benefits like improving communication and consensus-based decision-making were mentioned along with a supporting the development of an innovation strategy and learning about roadmapping.

10.3 Limitations and future research

There are also limitations to the performed research. The first limitation is the use of physical and online workshops in the designed TRM method. Due to the COVID-19 pandemic, the first three of the four workshops were held online, and the last one could be held physically due to the relaxation of the restrictions. If there had been no pandemic, all the workshops would have been hosted physically as that would have been the default way. Although all physical workshops would not have been necessarily better, a workshops series designed for all physical meetings would have resulted in the use of different tools and schedules in the designed TRM method compared to the design designed during this study.

The second limitation has to do with Sweco and the specialist group as representatives of the engineering consulting industry. This study assumed Sweco and the specialist group could serve as representatives of the problem context. Sweco is not the only engineering consultancy firm, there are other engineering consultancy firms, i.e. Arcades, or Royal HaskoningDHV. The researcher assumed they have the same innovation adoption problems as Sweco has, based on the paper by Eriksson (2013). However, this might not be the case as this was not be checked due to time constraints. A recommendation for future research would thus be to investigate whether there are indeed other engineering consultancy firms dealing with the same innovation strategy problems and whether the designed TRM method would also serve as a solution to their problems.

In future studies, the effect of the designed TRM method in other industries should be investigated. This study limited itself to only the engineering construction industry. However, the designed TRM method might also be applicable in other service-oriented industries which work on a project-bases for customers with similar innovation exploration and exploitation balancing problems. The recommendation would be, once a potential new service-oriented organisation has been found, to investigate the fit of the designed TRM method as a potential solution to the problem by imagining going through all the workshop steps with a team of experts from the organisation. If the tools would indeed help the experts in acquiring the sort after ins and outputs required in the workshops than the recommendation would be to proceed with a full implementation of the designed TRM method.

The second suggestion for future research is to proof the validity of the designed TRM method for different group sizes. It was out of the scope of this study to test the designed TRM method in more than one size team. This study used a team of seven people. The designed TRM method should be applied in teams of different sizes to determine whether the designed TRM method would still be valid. As a start, the same method could be applied within different specialist groups at Sweco. This will prevent interference in the result from changing organisations where the designed TRM method is applied in.

A third suggestion for future research is to investigate the effect of the designed TRM method on the balance between exploration and exploitation of innovations in the organisation. This was also outside of the scope of this study, but it would be interesting to investigate how much it changes the balance. A recommendation would be to compare the hours per week spend by the team on the exploration and the exploitation of innovations before and after the workshops in conjunction with the satisfaction with the innovations from both the team of experts and the customers of the organisation. By keeping track of these number for three to five years minimal, as innovations need to be developed and implemented, the long-term effect of the designed TRM method on the team's innovation strategy can be determined. Engineering consultancies keep a precious record of all the hours the employees spend on different activities and projects, the previous years can serve as a baseline for the balance in hours spend on the exploration and exploitation of innovations. The reason to take the satisfaction of

the innovations into considerations is to know when a balance between innovations exploration and exploitation is achieved.

10.4 Practical recommendations

When an engineering consultancy wishes to use the designed TRM method, one thing is important before even starting with the preparations of the workshops and that is that employees and management both have to be aware of the need to develop an innovation strategy. This was not a problem in the case described in chapter 9.1 The implementation of the designed TRM method in specialist group 'transmission pipelines' at Sweco, as everybody was already aware of this need. That is why emphasis is placed on the importance right here. Once everybody involved has gone through the acceptance process of the chances that will come from the innovation strategy. Employees and management can support each other and start the development of the innovation strategy.

A second recommendation is to host the workshops physically. Spontaneous interaction becomes more natural when the participants were all physically attending the workshops; conversions happened and flowed much more naturally. This was noticeable in the fourth workshop as it was hosted physically. The participants were more proactive than the online workshops, helping each other when someone did not understand what needed to happen. Also, the formation of smaller groups where people would deliberate someone amongst each other happened spontaneously.

The third piece of advice is to keep working at the innovation strategy after finishing the technology roadmap. It might be tempting for some organisation, especially for organisations that used the designed TRM method to develop their first innovation strategy, to put the technology roadmap in a drawer once the shine wears off to never look at it again. For those organisations, the end of the fourth workshop is just the beginning of a change in organisational culture. A first step is made, but the real change still has to take place as the innovation strategy needs to be executed. Start planning and executing the exploration activities that are written down on the technology roadmap. In parallel, start incorporating the designed TRM method into the business, by deciding when and how often the technology roadmap needs to be revisited to incorporate new developments that happened in the industry and to check whether the exploration activities that were planned, have been executed.

11 Conclusion

The goal of this study was to design a TRM method that would allow engineering consultancy firms to develop their innovation strategy. The deliverable of this study looked as follows:

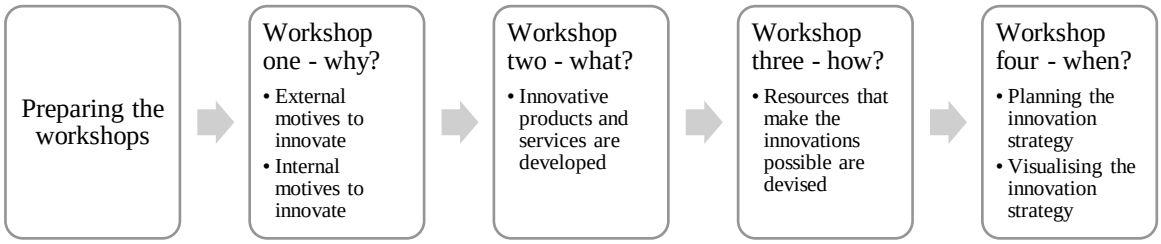


Figure 19. Overview of the designed TRM method.

This study designed a method that helps engineering consultancies develop their innovation strategies. The designed TRM method starts with preparing the workshops. The workshops need to be customised to organisations aim and the participants need to be informed about the upcoming workshops. The designed method has four workshops, each taking half a day. The first workshop – workshop one - why? – looks into the motives to innovate, these motives are based on customers and the team themselves. These motives are grouped into the innovation drivers which are used in the second and last workshop. In the second workshop – workshop two - what? – the participants define the products or services which need to innovate, the innovation elements. These innovation elements are going to be offered to the market, satisfy the innovation drivers. The third workshop – workshop three - how? – requires the participants to define and develop the resources, i.e. the people, or equipment, that make innovation exploration possible. Finally, during workshop four - when?, the technology roadmap is formed, adding a time component to the innovation drivers, elements and resources and plotting them on a single timeline, the technology roadmap.

Design science by Wieringa (2014) was used to achieve the goal by completing two consecutive but different design cycles, as shown in Figure 20. The first cycle started with the problem investigation, during which the goal mentioned above was formulated. The goal was turned into requirements in the following step, the treatment design. Next to the requirements, a treatment for the problem was designed through a literature study. The design verification in the first design cycle took place by verifying the requirements from chapter 5.1 Requirements for the designed TRM method. Six of the seven requirements could be verified; the seventh requirement required more operational details to be added to the designed TRM method before it could be verified.

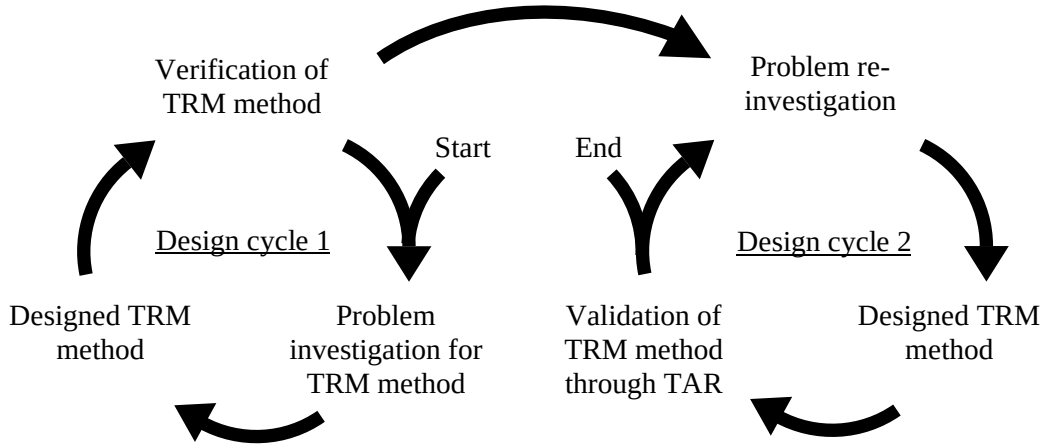


Figure 20. The two design cycles by which the designed TRM method was developed.

The second design cycle was thus entered to add more operational detail to the designed TRM method. Next to this new goal, a different validation method would be used, Technical Action Research (TAR). With TAR, the designed treatment was implemented in the real world to learn from the

experience and help the client, Sweco. During the treatment design of the second design cycle, the goals added in the previous step were turned into two additional requirements.

The validation in the second design cycle was done via TAR. With TAR, the designed TRM method was used in a real-world case to validate whether the requirements were met by the designed treatment, the application of the designed TRM method. The specialist group at Sweco served as the client that could provide the real-world problem to be solved by the designed TRM method. The designed TRM method was prepared for the specialist group, and four half-day workshops took place. Applying the designed TRM method allowed for the validation of the requirements drafted up during both the problem treatments.

The implementation was evaluated through three one-on-one interviews with three of the participants. The participants were asked five questions about the process they were part of to see if the designed TRM method functioned as intended, the questions can be found in chapter 3.2.3 Treatment validation. The interviewees indicated that the impact of technological developments internal and external to the organisation were discussed and the designed TRM method let them to the formation of the innovation strategy. Therefore, the researcher concluded that the implementation was successful, and it was used to validate the designed TRM method.

All nine requirements, as specified in chapter 5.1 Requirements for the designed TRM method and 8.1 Additional requirements for the designed TRM method were checked by the researcher against the implementation of the TRM method in the specialist group at Sweco and the implementation was found to satisfy all nine requirements. The conclusion was thus drawn that this study not only designed a TRM method to support engineering consultancies in the development of their innovation strategy but also that the designed TRM method satisfies the requirements to develop an innovation strategy in a real-world context.

12 References

Barker, D., & Smith, D. J. H. (1995). Technology foresight using roadmaps. *Long Range Planning*, *28*(2), 21-28. https://doi.org/10.1016/0024-6301(95)98586-H

Cosner, R. R., Hynds, E. J., Fusfeld, A. R., Loweth, C. V., Scouten, C., & Albright, R. (2007). Integrating Roadmapping into Technical Planning. *Research-Technology Management*, *50*(6), 31-48. https://doi.org/10.1080/08956308.2007.11657471

Eriksson, P. E. (2013). Exploration and exploitation in project-based organizations: Development and diffusion of knowledge at different organizational levels in construction companies. *International Journal of Project Management*, *31*(3), 333-341. https://doi.org/10.1016/j.ijproman.2012.07.005

Gerdsri, N. (2007). An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies. *International Journal of Innovation and Technology Management*, *4*(2), 121-135. https://doi.org/10.1142/S0219877007001004

Gerdsri, N., Assakul, P., & Vatananan, R. S. (2010). An activity guideline for technology roadmapping implementation. *Technology Analysis & Strategic Management*, *22*(2), 229-242. https://doi.org/10.1080/09537320903498553

Gerdsri, N., Puengrusme, S., Vatananan, R., & Tansurat, P. (2019). Conceptual framework to assess the impacts of changes on the status of a roadmap. *Journal of Engineering and Technology Management*, *52*, 16-31. https://doi.org/10.1016/j.jengtecman.2017.12.001

Gerdsri, N., Vatananan, R. S., & Dansamasatid, S. (2009). Dealing with the dynamics of technology roadmapping implementation: A case study. *Technological Forecasting and Social Change*, *76*(1), 50-60. https://doi.org/10.1016/j.techfore.2008.03.013

Groenveld, P. (1997). Roadmapping Integrates Business and Technology. *Research-Technology Management*, *40*(5), 48-55. https://doi.org/10.1080/08956308.1997.11671157

Grossman, D. S. (2004). Putting Technology on the Road. *Research-Technology Management*, *47*(2), 41-46. https://doi.org/10.1080/08956308.2004.11671618

Hobday, M. (2000). The project-based organisation: an ideal form for managing complex products and systems? *Research Policy*, *29*(7), 871-893. https://doi.org/10.1016/S0048-7333(00)00110-4

Kappel, T. A. (2001). Perspectives on roadmaps: how organizations talk about the future. *The Journal of Product Innovation Management*, *18*(1), 39-50. https://doi.org/10.1016/S0737-6782(00)00066-7

Kaur, K., & Kaur, M. (2010). Innovation Diffusion and Adoption Models: Foundation and Conceptual Framework. *Management and Labour Studies*, *35*, 289 - 301. https://doi.org/10.1177/0258042X1003500209

Kerr, C., & Phaal, R. (2015). Visualizing Roadmaps: A Design-Driven Approach. *Research-Technology Management*, *58*(4), 45-54. https://doi.org/10.5437/08956308X5804253

Kerr, C., Phaal, R., & Thams, K. (2019). Customising and deploying roadmapping in an organisational setting: The LEGO Group experience. *Journal of Engineering and Technology Management*, *52*, 48-60. https://doi.org/10.1016/j.jengtecman.2017.10.003

Kostoff, R., & Schaller, R. (2001). Science and technology roadmaps. *IEEE Trans. Engineering Management*, *48*, 132-143. https://doi.org/10.1109/17.922473

Lindblad, J. P. (2003). A Review and Critique of Rogers' Diffusion of Innovation Theory as it Applies to Organizations. *Organization Development Journal*, *21*(4), 50-64.

Lischka, J.-M., & Gemunden, H. G. (2008). Technology roadmapping in manufacturing: a case study at Siemens AG. *International Journal of Technology Intelligence and Planning (IJTIP)*, *4*(2), 201-214. https://doi.org/10.1504/IJTIP.2008.018317

McCarthy, J. J., Haley, D. J., & Dixon, B. W. (2001). Science and technology roadmapping to support project planning. *PICMET '01. Portland International Conference on Management of Engineering and Technology. Proceedings Vol.1: Book of Summaries (IEEE Cat. No.01CH37199)*, *2*(1), 637-649. https://doi.org/10.1109/PICMET.2001.952278

O'Reilly, C. A., & Tushman, M. L. (2008). Ambidexterity as a dynamic capability: Resolving the innovator's dilemma. *Research in Organizational Behavior*, *28*, 185-206. https://doi.org/10.1016/j.riob.2008.06.002

Park, H., Phaal, R., Ho, J.-Y., & O'Sullivan, E. (2020). Twenty years of technology and strategic roadmapping research: A school of thought perspective. *Technological Forecasting and Social Change*, *154*. https://doi.org/10.1016/j.techfore.2020.119965

Phaal, R., Farrukh, C., & Probert, D. (2001). Technology Roadmapping: linking technology resources to business objectives. 1 - 18.

Phaal, R., Farrukh, C., & Probert, D. (2004a). Customizing Roadmapping. *Research-Technology Management*, *47*(2), 26-37. https://doi.org/10.1080/08956308.2004.11671616

Phaal, R., Farrukh, C., & Probert, D. R. (2013). Fast-Start Roadmapping Workshop Approaches. In *Technology Roadmapping for Strategy and Innovation*. Springer. https://doi.org/10.1007/978-3-642-33923-3

Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2004b). Technology roadmapping—A planning framework for evolution and revolution. *Technological Forecasting and Social Change*, *71*(1-2), 5-26. https://doi.org/10.1016/s0040-1625(03)00072-6

Phaal, R., Farrukh, C. J. P., & Probert, D. R. (2007). Strategic Roadmapping: A Workshop-based Approach for Identifying and Exploring Strategic Issues and Opportunities. *Engineering Management Journal*, *19*(1), 3-12. https://doi.org/10.1080/10429247.2007.11431716

Phaal, R., & Muller, G. (2009). An architectural framework for roadmapping: Towards visual strategy. *Technological Forecasting and Social Change*, *76*(1), 39-49. https://doi.org/10.1016/j.techfore.2008.03.018

Phaal, R., Routley, M., Athanassopoulou, N., & Probert, D. (2012). Charting Exploitation Strategies for Emerging Technology. *Research-Technology Management*, *55*(2), 34-42. https://doi.org/10.5437/08956308X5502021

Phaal, R., Simonse, L., & Ouden, E. D. (2008). Next generation roadmapping for innovation planning. *International Journal of Technology Intelligence and Planning (IJTIP)*, *4*(2), 135-152. https://doi.org/10.1504/IJTIP.2008.018313

Rogers, E. M. (1971). *Diffusion of Innovations*. The Free Press.

Saritas, O., & Burmaoglu, S. (2016). Future of sustainable military operations under emerging energy and security considerations. *Technological Forecasting and Social Change*, *102*, 331-343. https://doi.org/10.1016/j.techfore.2015.08.010

Son, H., Lee, S., & Kim, C. (2015). What drives the adoption of building information modeling in design organizations? An empirical investigation of the antecedents affecting architects' behavioral intentions. *Automation in Construction*, *49*, 92-99. https://doi.org/10.1016/j.autcon.2014.10.012

Strauss, J. D., & Radnor, M. (2004). Roadmapping for Dynamic and Uncertain Environments. *Research-Technology Management*, *47*(2), 51-58. https://doi.org/10.1080/08956308.2004.11671620

Vishnevskiy, K., Karasev, O., & Meissner, D. (2015). Integrated roadmaps and corporate foresight as tools of innovation management: The case of Russian companies. *Technological Forecasting and Social Change*, *90*, 433-443. https://doi.org/10.1016/j.techfore.2014.04.011

Vishnevskiy, K., Karasev, O., & Meissner, D. (2016). Integrated roadmaps for strategic management and planning. *Technological Forecasting and Social Change*, *110*, 153-166. https://doi.org/10.1016/j.techfore.2015.10.020

Wells, R., Phaal, R., Farrukh, C., & Probert, D. (2004). Technology Roadmapping for A Service Organization. *Research-Technology Management*, *47*(2), 46-51. https://doi.org/10.1080/08956308.2004.11671619

Wieringa, R. J. (2014). *Design science methodology for information systems and software engineering*. Springer. https://doi.org/https://doi-org.ezproxy2.utwente.nl/10.1007/978-3-662-43839-8

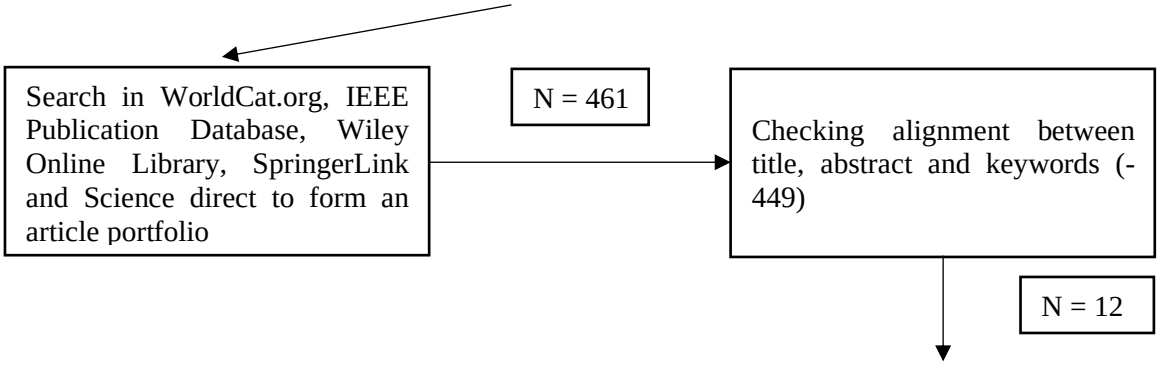
Appendix A: TRM literature searched for engineering consultancy

The gap in the TRM literature was investigated through bibliometric research. The search string shown in Table 8 was used in the search. It was made up out of ‘technology roadmapping’ and ‘innovation strategy’ and the industry ‘engineering consultancy’ or ‘service industry’. The term ‘service industry’ was added to enlarge the chance of finding papers that would invalidate the gap.

The search string was entered in WorldCat.org, IEEE Publication Database, Wiley Online Library, SpringerLink, and Science direct. This yielded 461 hits as shown in Figure 21. After checking the alignment between the title, paper and abstract the number of papers that would potentially fit came down to twelve. Next, the abstracts were red and another ten were removed from the group of potential papers. After reading the two remaining papers fully, the two remaining papers were also discarded. However, these two papers cited two interesting papers, after reading those fully, they were also discarded. The conclusion could be drawn that the number of articles regarding technology roadmapping and innovation strategies or engineering consultancy was determined to be zero.

Table 8. Search string used in bibliometric research.

Keywords domain	Keywords	Search string	Searching in	Justification
Technology roadmapping	Technology Roadmapping TRM	("Technology roadmapping" OR "technology roadmap" OR TRM) AND (Engineering* OR Consultancy* OR "Service* (industry* OR organisation*)") AND (innovation* AND strategy*)	Title, abstract, keyword	Connection between the main words was expended with the abbreviation of technology roadmapping. The term service industry and organisation were added as engineering consultancy is part of the service industry and an organisation providing engineering consultancy is a service organisation.
Industry	Engineering Consultancy Service industry Service organisation			
Innovation strategy	Innovation strategy			



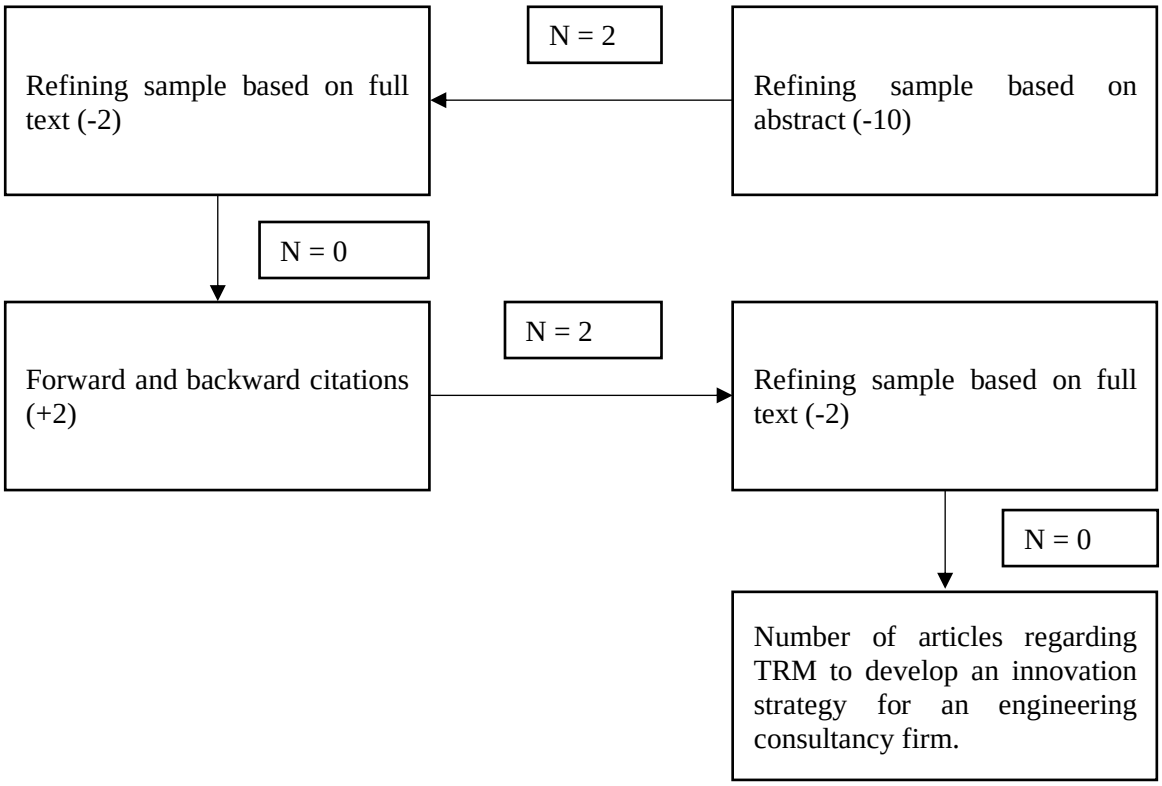


Figure 21. Bibliometric research process.

Appendix B: TRM implementation

Trying to make TRM part of the organisations ongoing business is a task that should not be taken lightly, as an incorrect implementation will result in an unsustainable TRM process (Gerdsri, 2007; Gerdsri et al., 2009; Phaal et al., 2001; Phaal et al., 2004b; Strauss & Radnor, 2004). As Phaal et al. (2007) mention, it can take several years and many iterations before the full benefits of TRM are realised. The participants are required to obtain new skills and an organisation new capabilities to implement TRM successfully (Kostoff & Schaller, 2001; Strauss & Radnor, 2004).

Cosner et al. (2007) and Gerdsri et al. (2010) argue for a change management approach to minimise the resistance posed by staff due to the changes made to the ongoing business processes. Gerdsri et al. (2010) look at the ADKAR model and Kotter's model to aid the TRM implementation.

In the first phase of the designed TRM method, the preparing the workshops, it is important to make practitioners part of the development. Getting everyone involved creates a shared sense of urgency and a shared vision. The change management approach would support the change in culture and structure (Cosner et al., 2007) resulting in an organisation that can cope with the new processes and procedures (Gerdsri et al., 2010).

For the integration in the day-to-day operations, the ADKAR model focuses on 'reinforcement'. Reinforcements in an organisational sense are celebratory moments, rewards, or recognition. Individual reinforcement is the satisfaction level with personal achievements or benefits derived from the change. Kotter's model emphasizes using quick wins to achieve more change in the desired direction and anchoring the change, which is now become the new approach, in the culture of the organisation.

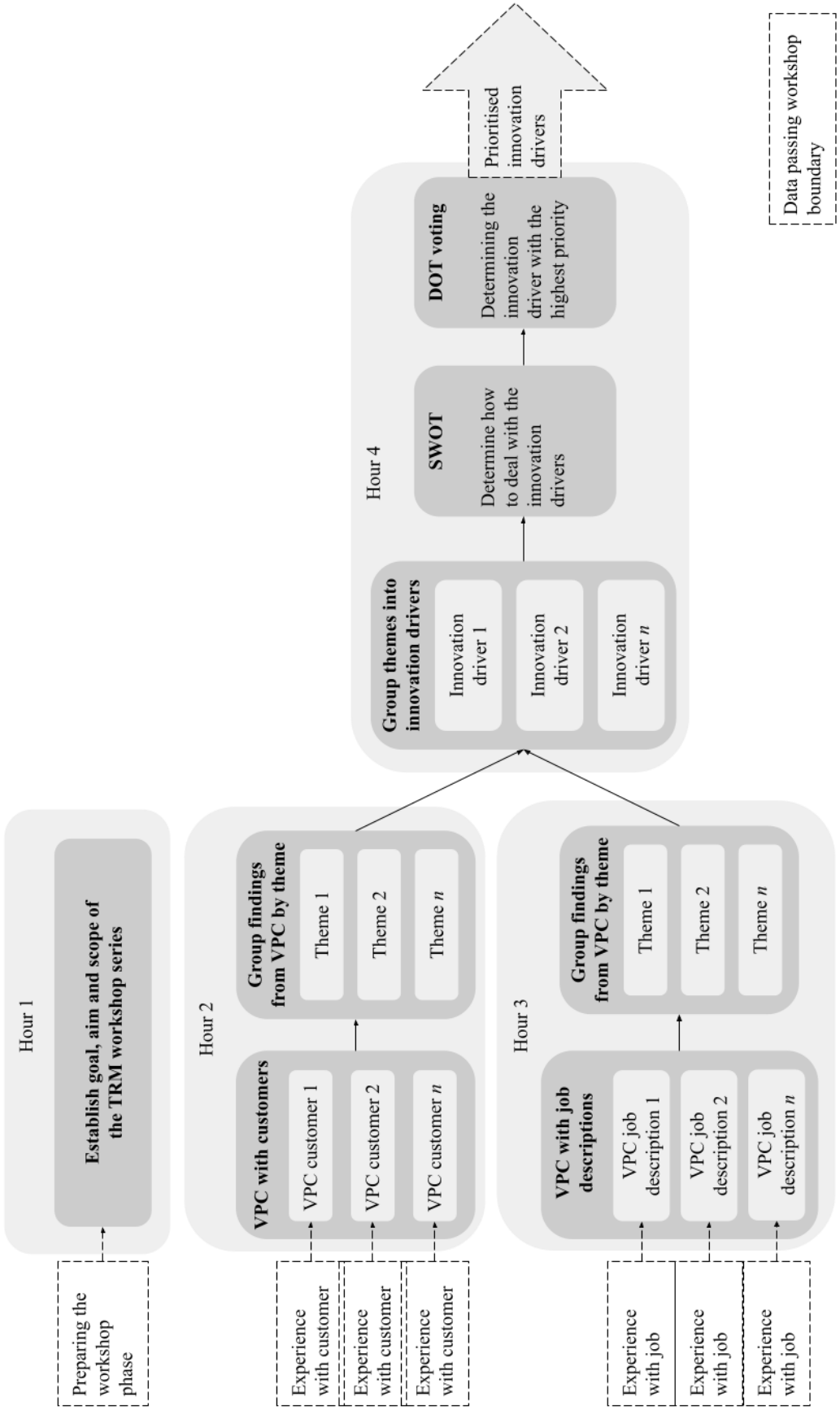
The success of the implementation should not be measured by the number of roadmaps in place, as Kappel (2001) warns for a misrepresentation: "This measure [number of roadmaps in place] represents both an overcounting, because it includes roadmaps that exert no real influence, and an undercounting because it misses the roadmaps that exerted one-time influence in a critical period." (p. 49). Gerdsri et al. (2010) proposes that the success can be measured in one of two ways: "through the quality of the alignment between the technology roadmaps and the corporate strategic plan, as well as the continuation of roadmapping on a day-to-day basis." (Gerdsri et al., 2010, p. 231)

Monitoring the technology roadmap status is an important procedure that has to be part of the business process (Gerdsri et al., 2019). Monitoring ensures the technology roadmap is adjusted to internal change like a change in the organisation's strategy or being able to react and adapt the technology roadmap to external factors (Kappel, 2001; Kostoff & Schaller, 2001; Strauss & Radnor, 2004). One external factor Cosner et al. (2007) warns for roadmaps is that roadmaps do not reflect the true customer need. Gerdsri et al. (2019) developed a cycle consisting of five steps to monitor and keep the technology roadmap up to date: 1) Apply the technology roadmap, 2) Monitor, 3) Assess, 4) Generate TRM status signal and 5) Management decision making. After which it loops back to step one.

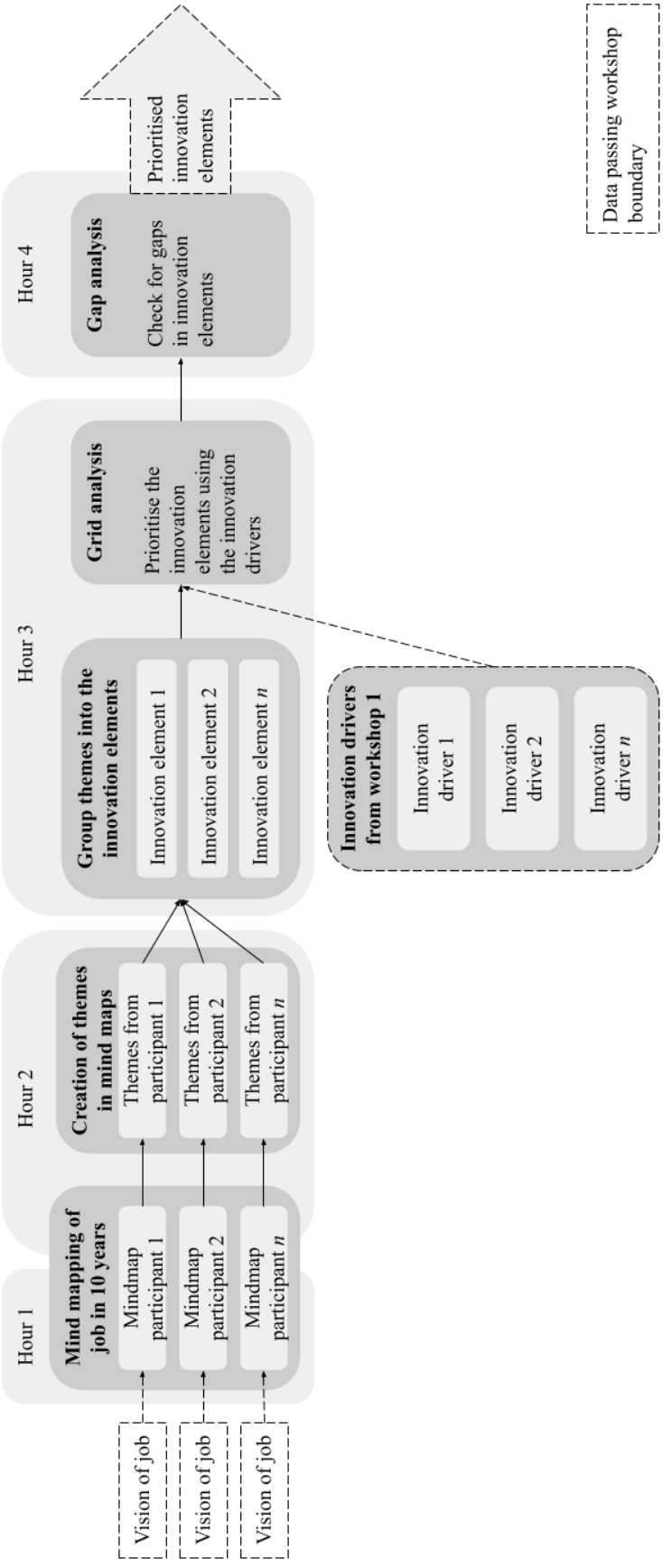
Implementing TRM in ongoing business processes is not easy, it involves changing the way people do their work. This requires change management to adapt the current culture to accept the new processes and procedures. Part of implementing TRM is keeping the technology roadmap up to date. A well-adjusted TRM tool will make it easier to monitor the technology roadmap.

Appendix C: Workshop in and outputs

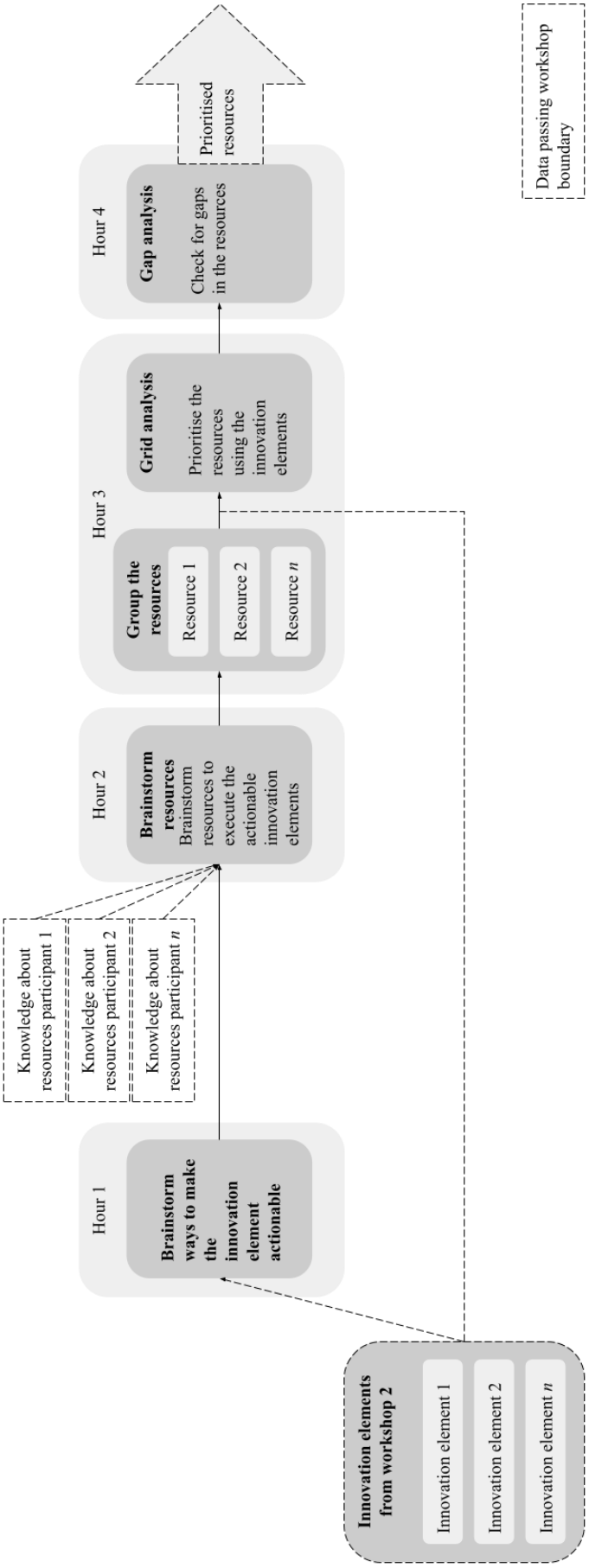
Workshop 1 – Why?



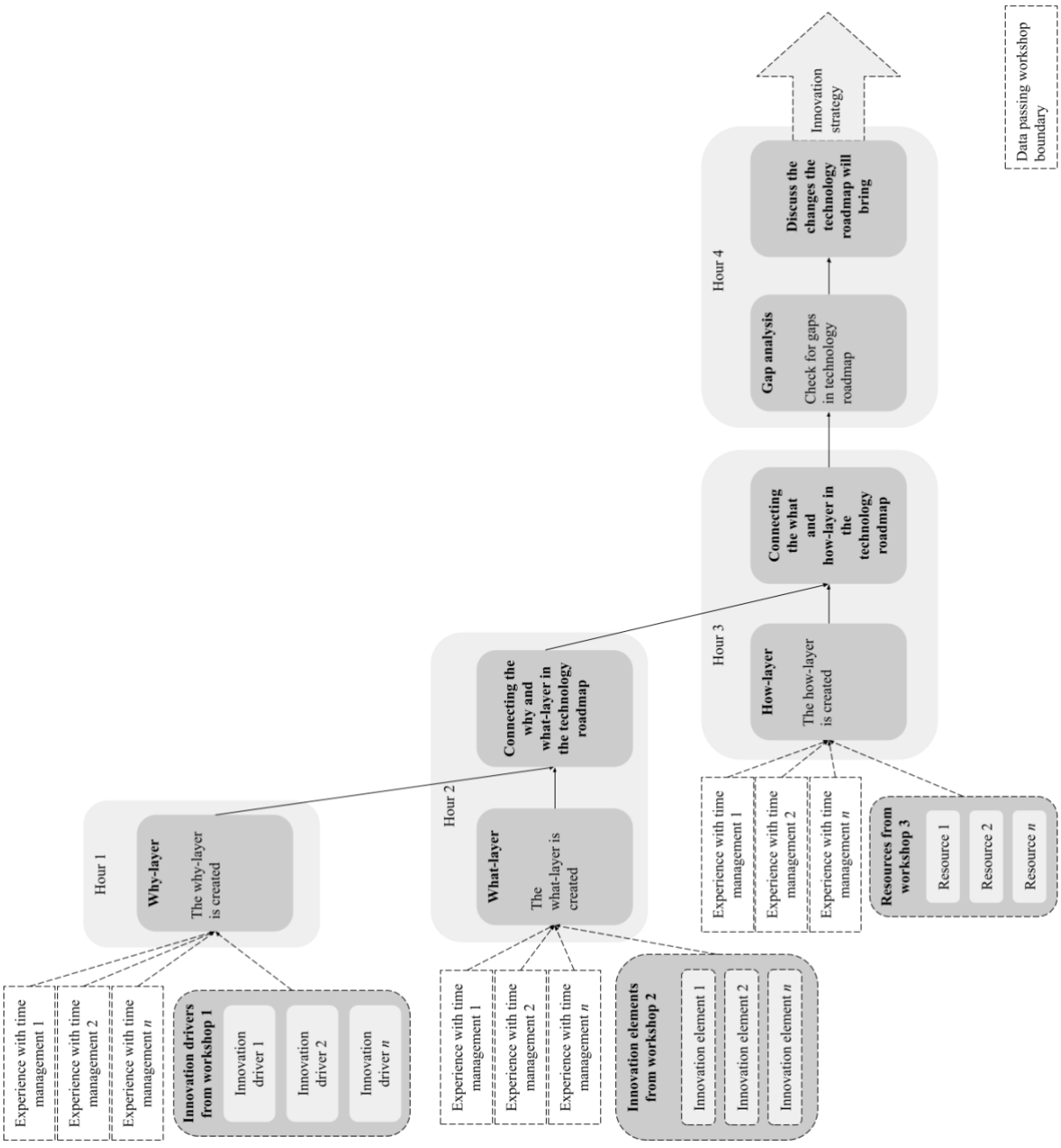
Workshop 2 – What?



Workshop 3 – How?



Workshop 4 – When?



Appendix D: Interview guide evaluation designed TRM method

Introductie	
Intro	Kort gesprek om technology roadmap workshops weer op te halen.
Doel van het interview	Aan de hand van de antwoorden op de gestelde vragen kan ik via criteria die ik aan het begin van mijn onderzoek aan de TRM tool gesteld heb controleren of de TRM tool op het eerste gezicht een TRM tool is.
Onderwerp	De workshops; zowel de 3 online workshops als de ene online workshop.
Anonimiteit en vertrouwelijkheid	Dit interview is anoniem, dat wil zeggen dat je persoonlijke gegevens enkel geanonimiseerd gebruikt of genoemd zullen worden in wetenschappelijke rapportages. Daarnaast zullen de dingen die je mij vertelt en de informatie die je mij geeft alleen voor dit onderzoek gebruikt worden.
Opname	Zoals je ziet heb ik opnameapparatuur meegenomen, waarmee dit gesprek wordt opgenomen. Vanuit de wet is voorgeschreven dat ik je, wel eerst om toestemming moet vragen als ik gebruikmaak van opnameapparatuur. Daarom vraag ik je zo meteen, als de recorder loopt, of u toestemming geeft dat dit gesprek wordt opgenomen. **Vind je het goed dat dit gesprek wordt opgenomen?**

Kern	
Vraag 1:	Hoe hielp technology roadmapping bij het in kaart brengen van externe invloeden op de innovatiestrategie?
Vraag 2:	Hoe hielp technology roadmapping de interne ontwikkelingen mee te nemen in de innovatiestrategie?
Vraag 3:	Heeft technology roadmapping geholpen de innovatiestrategie te plannen? Leg eens uit.
Vraag 4:	Hoe vond je dat de technology roadmapping tool de kennis opving en visualiseerde?
Vraag 5:	Heeft de techonlogy roadmapping tool geholpen bij het verbeteren van de interne communicatie en het op één lijn brengen van het team? Leg eens uit.

Afsluiting	
Afsluiting interview	Heb je het idee dat ik na aanleiding van de gestelde vragen nog iets vergeten ben te vragen?
Beschrijving van wat ik met de informatie ga doen	Citaten uit dit interview zullen gebruikt worden als onderbouwing waarom de gebruikte TRM tool wel of niet aan de gestelde criteria voldoet.

Appendix E: Innovation Diffusion Theory

An innovation is described by Roger E.M. as “an idea, practice, or object that is perceived as new by an individual or other unit of adoption” (Rogers, 1971, p. 11). Innovation are adopted in an organisation by a process called diffusion. Diffusion is defined by Rogers as “the process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 1971, p. 5). To describe the process of innovation diffusion through social systems, like organisations, Rogers designed the IDT. The theory describes how an individual design making unit goes through the process, shown in Figure 22, of adoption or rejection of an innovation.

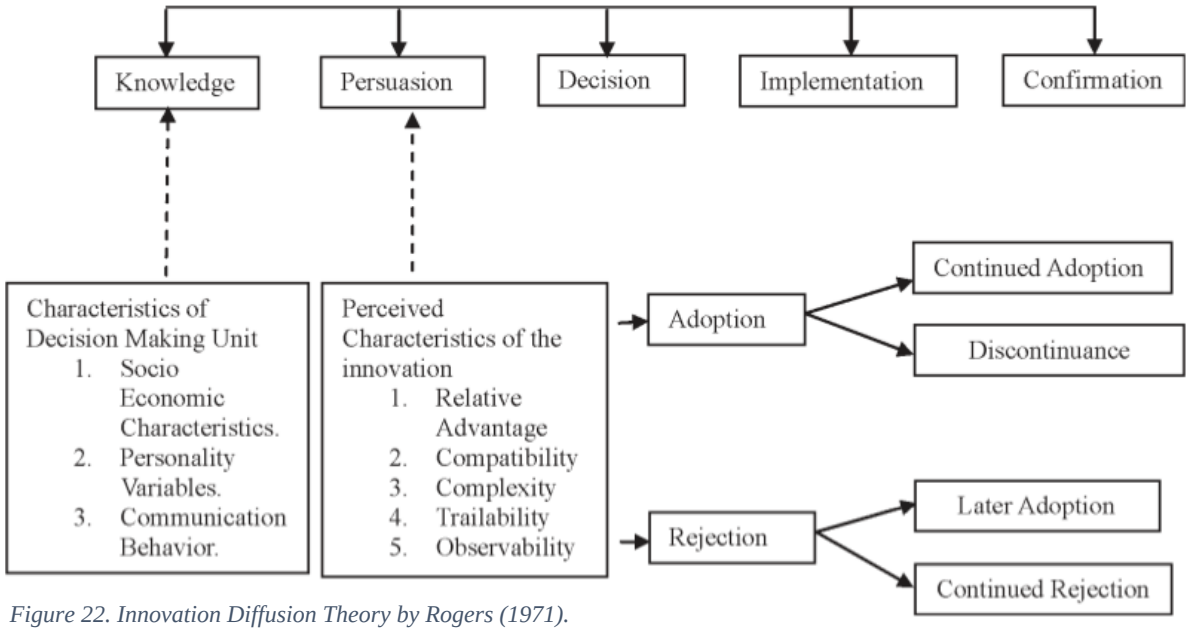


Figure 22. Innovation Diffusion Theory by Rogers (1971).

Table 9. Characteristics of the five stage of the IDT.

Term	**Description**
Knowledge	In this stage the decision making unit is becoming aware of the innovation and how the innovation works (Kaur & Kaur, 2010).
Persuasion	The decision making unit makes a prediction of the effect of the innovation in the decision making units current situation and tries to anticipate the effect on future situations (Lindblad, 2003).
Decision	Based on this mental model formed during the previous stage, the decision making unit decides whether to adopt or reject the innovation (Kaur & Kaur, 2010).
Implementation	The innovation is fully adopted and the decision making unit can start to analyse and form an opinion about the usefulness of the innovation. S/he can also decide whether the initial perception of the innovation was true or not (Kaur & Kaur, 2010).
Confirmation	In the last stage the decision making unit is strengthened by its choice. As the adoption process is an ongoing process, the adoption is reaffirmed or rejected depending on factors in and out of the decision makings units influence (Rogers, 1971).

The individuals in a social system do not adopt the innovation at the same time according to Rogers (1971). He claims there are five categories, shown in Table 10, individuals can fall in when it comes to the adoption and implementation speed of innovation in their life-style.

Table 10. Adopter categories and key features by Roger (1971).

Adopter category	**Key features**	**Percentage of total population that are likely to adopt**
Innovators	Are very eager to try new ideas and are willing to take risk to do so. Communication among innovators is high.	2,5 %
Early adopters	These types are more integrated into local social systems and are a role model. A person to check before he or she adopts.	13,5 %
Early majority	Adopts new ideas just before the average time a person would adopt. Seldom holds a leadership position and deliberates before adopting.	34 %
Late majority	Adopts new ideas just after the average time. Adoption may be an economic reason or reaction to peer pressure. Very cautious around innovations.	34 %
Laggards	Adopt innovations at the last stage. Oriented to the past and suspicious of the new.	16 %

Appendix F: Design cycle by Wieringa (2014)

The different steps form the design cycle are outlined below:

- Problem investigation: the researcher explored the problem context to understand and map the cause(s) of the problem. Often, this is obscured by information that is not relevant to the problem. By removing the obscuring information, the researcher ends up with a problem definition that only consists of the problem and not the symptoms.
- Treatment design: the artifact under design was the designed TRM method. An artifact is something that is created by people with a practical purpose (Wieringa, 2014).
- Treatment validation: During the treatment validation the researcher had to justify whether the proposed artifact would contribute to the goals set by the stakeholders.

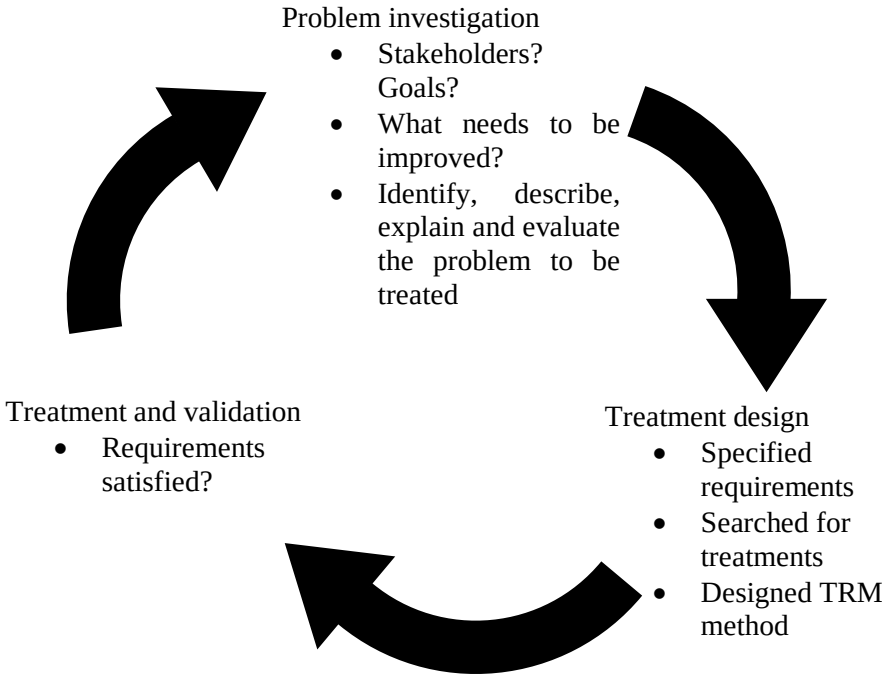


Figure 23. The design cycle by Wieringa (2014), filled out to suit this study.