Decision Support Framework for managing innovation portfolios

Delft, The Netherlands
18-08-2017

Thesis submitted to
Delft University of Technology

In partial fulfilment of the requirements for the degree of
MASTER OF SCIENCE

In Management of Technology
Faculty of Technology, Policy and Management

By
Mr. Fouad Saleem
Student number: 4181903

Disclaimer

Abstract

Decisions surrounding innovations are often made on a project-to-project basis, and therefore lose sight of the overview of projects, i.e. the portfolio, and fall short on their strategic orientation (Cooper et al., 2001b). The research explores how innovation portfolio management can benefit innovation decision-makers in private and public organisations. More specifically, the thesis emphasizes on how innovation portfolio management can be improved for both its own practice and the innovation management process in general. Innovation portfolio management is a process that enables innovating organisations to better allocate their resources, strategically align their innovation projects, and reach a healthier portfolio balance. The research approach for the exploration and exploitation of the process, is the design of an innovation portfolio management model, and an innovation support framework to help position the model in current practices.

Keywords: Innovation management, portfolio management, new product development, decision support system

Graduation Committee

Chairman: **Prof. Dr. Cees van Beers**
Department: Values, Technology and Innovation
Section: Economics of Technology and Innovation
TU Delft – Delft University of Technology

First Supervisor: **Dr. Dap Hartmann**
Delft Centre for Entrepreneurship
TU Delft – Delft University of Technology

Second Supervisor: **Dr. Mark de Bruijne**
Department: Multi-Actor Systems
Section: Policy, Organisation, Law & Gaming
TU Delft – Delft University of Technology

External Supervisor: **MSc. Menno van Rijn**
Managing Partner – Strategy Consulting
Bax & Company

Second External Supervisor: **Dr. Sebastiaan van Herk**
Partner – Strategy Consulting
Bax & Company

EXECUTIVE SUMMARY

Innovation is regarded a critical activity for organisations to survive and maintain a competitive advantage. The innovation process is often made with a lack of information, leading to uncertainties and risks. Organisations attempt to manage the process, so that little gets left to chance and the level of risk and uncertainty can be reduced. Innovation portfolio management (IPM) is a process that enables innovation decision-makers to manage their portfolio of innovation projects, and better allocate their resources to innovation, align their innovation projects with the organisation's strategy, and balance the types of innovations (i.e. industry, incremental or radical). Organisations often experience difficulty when it comes to Innovation portfolio management (Barczak, Griffin, & Kahn, 2009). Current innovation management models, remain too generic, static and don't illustrate the relationships with other innovation practices. This calls into question the current models in their application.

The research developed an innovation portfolio management (IPM) model. The IPM model was co-developed with opinion leaders (lead-users) to identify important modifications and improvements. The IPM model is made operational in an IT environment and consists of five methods that complement each other in supporting innovation managers in the process of innovation portfolio management decision-making. The IPM model helps innovation managers identify the risks and benefits of innovation projects and rank innovation projects. The IPM model helps to make sure the portfolio of innovation projects is always in balance (i.e. strategically aligned, right mixture of radical and incremental projects, and the portfolio does not go overbudget).

The research also accumulated knowledge and key elements from relevant innovation models and practices, and presented them in the form of an innovation support framework to help portfolio decision-makers integrate the innovation portfolio management process within their current innovation practices. This framework consists of six building blocks and illustrates the relationship and interdependencies between the many innovation management practices and external knowledge and information. The innovation support framework brings project management benefits, while presenting the innovation process as a circular and continuous process. The innovation support framework helps portfolio decision-makers to generate more novel and creative ideas, by incorporating external innovation stakeholders. As well as the generation of more successful innovation ideas (i.e. higher number of commercialized ideas), by providing more direction in the idea generation process through innovation portfolio management.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisors Dr. Dap Hartmann and Dr. Mark de Bruijne for their patience. Even though it has been a long and difficult journey for me, they were always willing to give critical feedback and help me learn and improve. I would also like to thank the chair Prof. Dr. Cees van Beers for his insights and willingness to always make time for me.

This project would nog have been possible without the cooperation of Bax & Company. I would like to thank my external supervisors MSc. Menno van Rijn and and Dr. Sebastiaan van Herk from Bax & Company and all the colleagues at the firm for their knowledge, expertise, faith, support, privileges and time. I would also like to thank Bernat Recasens Vert, director of Critflow, for his knowledge, expertise, time and the many talks and collaboration sessions we had. I would also like to thank each and every single expert who dedicated some time from their busy agenda to have a talk with me.

Last but not least, I would like to thank my family for their unconditional support. My loving parents to whom I dedicate this paper. I will never forget the sacrifices you made to make this bright future possible for me. No words can express my admiration and appreciation for you.

Fouad Saleem
Delft, The Netherlands
August, 2017

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ABBREVIATION

BI – Business intelligence
CIM – Cyclic Innovation Model
DSS – Decision Support System
GDSS – Group Decision Support System
IM – Innovation Management
IPM – Innovation Portfolio Management
KM – Knowledge Management
KMS – Knowledge Management System
MCDA – Multi-Criteria Decision Analysis
NPD – New Product Development
Product – Any tangible and non-tangible product mankind built
R&D – Research and Development

1 INTRODUCTION

The aim of this master thesis is to improve part of the innovation management process; the innovation portfolio management process. Firms continuously develop and introduce new products into the marketplace to obtain and maintain a competitive advantage, which is critical for business success (Chao & Kavadias, 2008; Eisenhardt & Martin, 2000). Continuously innovating means that the firm has multiple innovations in development at any point in time. Nonetheless, companies tend to make New Product Development (NPD) decisions on a project-to-project basis and lose sight of the overview on projects, i.e. the portfolio. It was more important to develop projects in the 'right' way than to develop the 'right' projects for most firms (Cooper, Edgett, & Kleinschmidt, 2001b).

The innovation portfolio management (IPM) process is characterized as a dynamic resource allocation process that takes into account the strategic considerations across projects in the portfolio and interdependencies between projects, while dealing with multiple decision makers who are often dispersed across locations (Chao & Kavadias, 2008; Cooper et al., 2001b).

Organisations that make poor choices regarding their innovation portfolio risk to lose their competitive advantage. The importance of effective IPM is illustrated by the example of how DuPont managed to survive in the long run by radically refocussing their innovation portfolio decision-making. DuPont went through a difficult period, because the firm spent most of its $2 billion Research and Development budget to improve established product lines. For a long time their low cost projects resulted in large volume products with little product variety in the portfolio (Barrett, 2003). The company then realised the effect and tried to shift towards a more open attitude against new business models and new partnerships (Chowdhry, 2010). Managing the portfolio of innovations helps organisations to identify these kind of imbalances (too much short-term orientation) and highlights the need for more radical long-term oriented projects to achieve a 'healthy' portfolio balance.

Another example is how Kodak shifted its resources towards improving existing technologies to catch up with the digital photography market. Even though Kodak was associated with photography for most of the twentieth century (Schoenberger, 2003), Kodak was afraid that digital photography would eat into its traditional most profitable business. However, the environment moved on and Kodak stayed behind. Kodak, as big as it was, could not control whether the change would happen or not. Consumers were ready for new innovations and chose to invest in the new and disruptive technology (Lucas & Goh, 2009). The company should have diversified its portfolio and invested in new technologies. The innovation portfolio management process helps organisations to identify the lack of diversification in the innovation portfolio and illustrates the strategic alignment of potential new radical developments (i.e. radical to the current innovation portfolio).

The cases of DuPont and Kodak, among many others, show that effective resource allocation and IPM have a large impact on the success of a firm (Cooper et al., 2001b). When managers make innovation portfolio decisions they make a difficult choice between risky investments, where resources are allocated to the development of fundamentally new technologies, riskier products and markets, to improve existing technologies, extend established product lines and strengthen the current market position without excessive risk. The unpredictability is mitigated by not “putting all eggs in one basket”.

The importance of innovation portfolio management (IPM) and its best practices have been recognized throughout several studies (Cooper, Edgett, & Kleinschmidt, 1999; Coulon, Ernst, Lichtenthaler, & Vollmoeller, 2009; Ernst & Lichtenthaler, 2009; Hunt et al., 2008; Phaal, Farrukh, & Probert, 2006). IPM requires data from various departments within and outside of an organisation (e.g. R&D, marketing and production). To gather this data and information, the IPM process usually utilises decision-support systems (Coulon et al., 2009). There is a growing number of innovation management tools and an increasing amount of data available (Cooper, Edgett, & Kleinschmidt, 2001a; Coulon et al., 2009). However, the IPM process is very contextual and it remains unclear how IPM can be supported. Current tools and methods tend to be too complex and not user friendly, leading to the tools’ disuse (Cooper et al., 2001b p.81; Coulon et al., 2009; Phaal et al., 2006). Research may give an indication on which methods and factors are truly important for the IPM decision-making process, and how the IPM process can be made operational within the context of its user. This information can then be used to contribute towards a solution that can support the management of innovation portfolios.

Section 1.1 introduces the commissioning organisation Bax & Company. Section 1.2 defines the problem, followed by the research objective and questions in Sections 1.3 and 1.4. Section 1.5 shows the envisioned deliverables. The practical and academic relevance are presented in Sections 1.6 and 1.7. Finally, the structure of the paper is laid out in Section 1.8.

1.1 Bax & Company

Bax & Company (B&C) is a consultancy, located in Barcelona, giving tailored new business development advise to commercial and public entities. The firm facilitates open innovation strategies for large organisations as well as smaller high-tech companies, research institutes and municipalities.

Innovation portfolio management (IPM) plays an important part in the consultancy’s activities. Several clients of B&C suffered from problems where the roots would find themselves in the unfamiliarity of Innovation Portfolio Management. To solve these problems, B&C developed a tool tailor-made for its clients. The tool would visualize the potential risks and rewards to the portfolio, resulting from innovation decisions. Over the years, the tool got outdated and was not capable of adapting to current innovation practices and thus did not meet customer needs anymore. Nonetheless, the firm recognized a need for an external IPM solution among its clients. Therefore, the consultancy decided to breathe new life into the project. An Innovation IT-firm called Critflow, recognized the same opportunity and decided to collaborate with B&C to develop an up-to-date solution. Critflow offers innovation management support by means of a tool called EasyCrit. However, the tool lacked support for IPM and required additional research to support the IPM process.

1.2 PROBLEM STATEMENT

The importance of Innovation portfolio management (IPM) activities for innovation success is emphasized by several studies (Cooper et al., 2001b; Coulon et al., 2009; Tidd & Thuriaux-Alemán, 2016). Tidd and Alemán (2016) argue that two out of the four innovation management practices significantly associated with superior innovation performance are: technology understood in terms of its quantified contribution to corporate goals and frequent review of portfolios. The first resolves around the strategic alignment of projects and allowing companies to regularly realign and reprioritize their technology investment portfolio to support corporate goals and reduce the loss of resources (waste) in technology development. The second involves having regular and structured reviews of the product portfolio to meet changes in the targeted segments. This enables organisations to optimize their resource allocation in line with these changes, remove waste from the portfolio of projects, and pull in new projects that align with the corporate strategy.

Figure 1 shows a number of consequences for organisations when they lack an IPM process. E.g. when firms initiate more NPD projects than their resources can support, portfolio overload occurs. This results in the phenomenon of “firefighting”; the unplanned allocation of resources to solve unanticipated problems that are discovered late in a product development cycle (Repenning, 2001). High-value long-term oriented projects are terminated because of budget restrictions. As a result, longer-term strategic goals are not met, because too many (wrong) low value projects were selected resulting in the depletion of the innovation budget. This results in higher failure rates and many project failures, which did not even have the opportunity to reach the market.

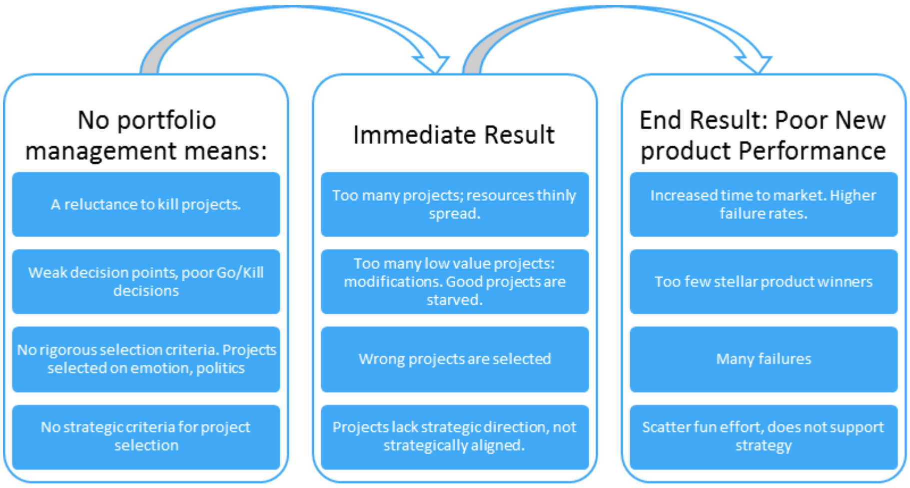


Figure 1 Results of bad innovation portfolio management (Cooper et al., 2001b)

Firms, however, often perceive difficulty with IPM. IPM solutions often tend to be too complex, effort demanding, and don’t integrate well with other deployed innovation management methods (Cooper et al., 2001b; Phaal et al., 2006). Scott (2001) also argues in his study, among eighty-four university and industry experts, that strategic planning and innovation project selection rank the highest among the difficulties associated with the management of innovation. Strategic planning resolves around the issues associated with strategic alignment, strategic decision-making, and new product introduction strategies. Innovation project selection involves issues with innovation project selection; criteria, establishment of a systematic approach for selection, and the inability of conventional financial evaluation methods to help evaluate innovations. There is limited knowledge available regarding the perceived importance and effectiveness of IPM practices in different industries (Tidd & Thuriaux-

Alemán, 2016). Also, it remains unclear to most organisations how the IPM process relates to the current innovation management practices. The problem of this paper is formulated as such:

Despite the importance of innovation portfolio management (IPM), there is no clear understanding how the IPM process can be operationalised, i.e. adapt to the user's context and integrate with the user's deployed innovation practices.

1.3 RESEARCH OBJECTIVE

To make clear what kind of knowledge the research will generate to contribute towards a solution, and how this contribution will be made, two research objectives are defined. The main research objective (RO) revolves around the development of a support framework, that illustrates how innovation portfolio management relates to other innovation practices. This framework helps innovation decision-makers to identify how the IPM process can be linked to other innovation practices, and when the IPM process needs to be performed within the innovation process. Understanding these linkages could help decision-makers better integrate IPM with their deployed innovation management practices and provide the ability to adapt the IPM process to their context. It is defined as follows:

> RO: *to give recommendations to the improvement of innovation portfolio management (IPM) practices, by identifying requirements, and designing an innovation support framework that can assist practitioners in positioning IPM in their innovation process.*

The support framework (RO) helps to position the innovation portfolio management process within the innovation management process. To gain a better understanding of how the innovation portfolio management process can be performed in the application domain, i.e. how the IPM process can be supported in an IT environment, a tool will be co-developed with potential users (lead-users) during the research project for in-depth feedback on the design and improvements. The tool, that takes on the form of a IPM tool, will run through iterative feedback loops to improve the design and allow for a better fit within the application domain. It is defined as the following sub-research objective (SRO):

> SRO: *design an innovation portfolio management model, that takes the form of a IPM tool and serves as a basis for further development together with lead-users in the application domain.*

1.4 RESEARCH QUESTIONS

To guide the research towards the objective and sub-objective, a central question is introduced. The central research question revolves around the development of an innovation portfolio management (IPM) framework that allows for agility and flexibility, and helps to better integrate the IPM process with the user's currently deployed innovation practices.

Understanding how the innovation portfolio management (IPM) process relates to other innovation practices, helps to better position and link the IPM process with other innovation practices. This allows for a better integration of the IPM process with user's currently deployed innovation practices. Understanding how the IPM model can adapt to the user's context, would provide the model with the agility and flexibility needed to reach a better fit with the user's innovation process. This would help to reduce the complexity and resource intensity needed to perform the IPM process. The central question, therefore, is defined as follows:

> RQ: What are the four most important criteria for an innovation portfolio management model, that can adapt to the user's internal and external environment and integrate with the user's current innovation practices?

The central question is unravelled in sub-questions, indicating which different types of knowledge are required to answer the central question. These sub-questions are defined as follows:

> *SRQ1: Which theories are linked to an Innovation Portfolio Management decision support system, capable of adapting to the user's context and integrating with the user's current innovation practices?*

The knowledge base surrounding the research objective is important because it provides the required knowledge to better understand the problem at hand, the importance of its solution and the theories that can be utilized in a solution and therefore help this research achieve rigor (more in Chapter 2).

> *SRQ2: What are the requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?*

The requirements help us to understand how the two artifacts (RO, SRO in Section 1.3) can build upon prior knowledge and achieve relevance in the application domain. The requirements serve as guidelines for the development of the models that were introduced in the research objectives.

> *SRQ3: To what extent do the currently employed solutions at the commissioning organisations, meet the identified requirements?*

To solve the problem at hand it is important to analyse if the current solutions meet the requirements defined in the previous research question. It is important to build on existing knowledge to help develop and achieve the two research objectives (Section 1.3). The successes and failures during their intervention can bring along new insights that are not obtainable in the theoretical domain.

> *SRQ4: What are the relevant criteria for an innovation portfolio management tool, that can serve as a basis for future co-development with lead-users in the application domain?*

The design principles are the accumulation of requirements and concepts obtained from the knowledge base and application domain, that serve to guide the design of the tool. Once a good overview of the theories on innovation portfolio management has been obtained, and the current solutions have been analysed, it is possible to design a first concept innovation portfolio management tool. The tool allows for close involvement from users in the application domain, and helps to reach a higher relevance. The design process will be an iterative process, in which the design will be developed, improved and evaluated several times. It is important to state that, since this is an iterative process, it requires the researcher to come back to the previous questions before reaching a satisfying end design.

> *SRQ5: What are the relevant criteria for an innovation support framework, that can adapt to the user's context and methodology and help position and integrate the innovation portfolio management model in current innovation management practices?*

With the relevant requirements and core principles at hand, it will be possible to design an innovation support framework that integrates the innovation portfolio management process (IPM) (and tool from SRQ4), to help users identify and position the IPM process in current innovation management practices. The framework illustrates the information and knowledge exchanges that occur between the innovation portfolio management process and other innovation practices.

The combined answers to these sub-questions provide a satisfactory answer to the central question.

1.5 DELIVERABLES

The deliverables that have been envisioned are:

1. The design requirements for an innovation portfolio management tool, that can guide companies through the process of innovation portfolio management.
2. An innovation support framework, capable of guiding practitioners in the application and implementation of an IPM model. The framework takes on an informative role and summarizes the decision-making around IPM and the use of multi-criteria decision-aiding methods.

1.6 ACADEMIC RELEVANCE

The practice-oriented research project serves both a theoretical and a practical goal, and directly or indirectly contributes to the knowledge base. The existing literature provides an incomplete picture of innovation portfolio management (IPM) practices; **(1)** the theory so far has been largely disconnected to other theories of innovation management and therefore fails to illustrate how IPM can integrate in current innovation management practices. **(2)** There is a lack of knowledge in which innovation portfolio management methods work and do not work in an application domain. Through the iterative development and demonstration of a concept innovation portfolio management model in the form of a tool in an IT environment, the research hopes to contribute towards more insights in the latter gap. The development of the artifacts mentioned in Section 1.5, together with the gathered data from the real world can contribute to gain a better understanding of these practices and help close the gap between theoretical research and real application.

1.7 PRACTICAL RELEVANCE

As mentioned in the previous Section, the research project also serves a practical goal. As will be further highlighted in Sections 2.1 & 2.2. The practical relevance in this design science research project is of high importance and thus the research will iteratively be reviewed and testes in the application domain. The practical relevance is to provide information and knowledge that can contribute towards solving the practical problem earlier defined in Section 1.2. The created knowledge (the artifacts and their development) is aimed to be used by practitioners in private and public organisations to contribute to a successful intervention of the innovation portfolio management process and improve the current innovation practices.

Developing an innovation portfolio management model in the form of a tool that executives can operate, would help make clear to the decision-maker that certain decisions, under specific criteria, are slightly better than other decisions. The development of an innovation portfolio management model and an innovation support framework supporting the model, can offer a starting point for the decision-makers to start thinking. Top level managers (CEO, board of directors) don't have the time and skills to understand the models that the decision-making academics can offer, however, very simple models can be very helpful as a starting point in strategic decisions for the senior managers. The outcome of the research will be beneficial to private and public organisations, as it can provide the innovation managers with the right set of tools to perform their innovation portfolio management process and avoid unnecessary risks and costs, resulting in a more efficient expenditure on innovation.

1.8 STRUCTURE

This paper is structured as followed. Chapter 2 explains the logic underlying the project design and the structure of this research. The structure of the following four Chapters and the research questions are illustrated in Figure 2. The illustration builds on the framework proposed by Hevner (2007) as a generic model (Section 2.2) and illustrates the main building blocks of this design research.

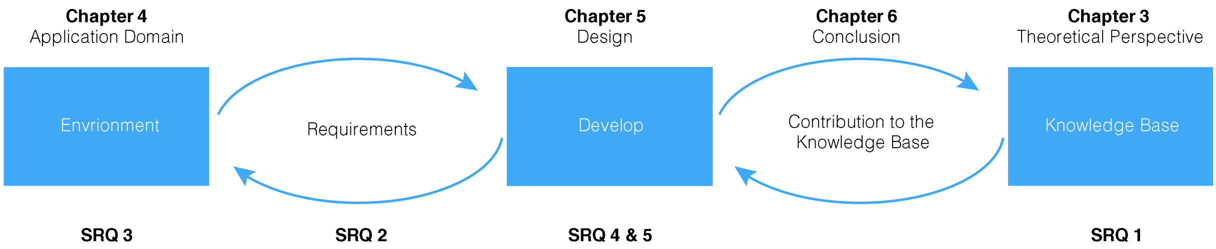


Figure 2 Research structure of this research project

2 RESEARCH DESIGN

Following the introduction to the research subject, the problem definition and the derived research objective, this Chapter will elaborate the research approach in more detail. The Chapter starts, by defining the research strategy and provides an overview of relevant research methodologies (Section 2.1). The following Sections further describe the chosen research methodologies: Hevner et al. Research cycles (Section 2.2), and Peffers et al. Research design process (Section 2.3). The Chapter ends by elaborating on the research structure used to reach the research objective (Section 2.4).

2.1 DESIGN-SCIENCE AS RESEARCH STRATEGY

The subject of the research project is part of a wider context. This context is placed within the environment of an organisation in which the research takes place, which makes it a practice-oriented approach. As the nature of the systems (innovation management support systems) this research will deal with is orientated towards information and data analysis and transfer, it seems appropriate to place the research within the 'Information Systems' discipline. As Peffers et al. (2006) arguments, "Information Systems (IS) is an applied research discipline where an explicitly applicable solution to a problem is created". The field of IS distinguishes itself from other fields, as is emphasized by Lee (2001), by examining "more than just the technological system, or the social system, or even the two next to each other; it investigates the phenomena that emerge when the two systems interact".

Shirley Gregor (2006) proposed a taxonomy that classifies Information Systems into five interrelated types of theories: **(1)** theory for analysing, **(2)** theory for explaining, **(3)** theory for predicting, **(4)** theory for explaining and predicting, **(5)** theory for design and action. The latter (theory for design and action) would seem the most appropriate for this research, since the theory gives explicit prescriptions for constructing an artifact (Gregor, 2006). An artifact is "something that is artificial, constructed by humans, as opposed to something that occurs naturally" (Simon, 1996 p. 5). Artifacts are created to improve existing solutions to a problem or to provide a novel solution to an important problem. The term artifact is used in this research, to refer to something that is transformed, or can be transformed into an artificially made object or process.

There are different views on design theory. Gregor (2006) shows that design theory has been referred to as software engineering research, constructive research, prototyping, systems development approach, and as design science. This research uses the design science approach, which has been given validity and importance in the Information Systems literature (Hevner, March, Park, & Ram, 2004; March & Smith, 1995). The Information Systems Design Science Research paradigm is fundamentally a problem-solving paradigm which addresses wicked organisational problems (Hevner & Chatterjee, 2010 p.11; Weber, 1987). These problems are characterized by:

- unstable requirements and constraints based on ill-defined environmental contexts,
- complex interactions among subcomponents of the problem
- inherent flexibility to change design processes as well as design artifacts
- a critical dependence on human cognitive and social abilities to produce effective solutions.

The innovation management process is fraught with technological, market and organisational uncertainties, resulting from the lack of information of the innovation process. The requirements and constraints surrounding the process are therefore subject to constant change. Furthermore, the many actors involved in the process poses complex relationships. The innovation process often involves internal and external stakeholders, requiring creative solutions that take the perspectives from the various stakeholders into consideration. Therefore the research paradigm of Information Systems Design Science Research seems appropriate, which calls for the creation of innovative artifacts to solve real-world problems containing a high priority on the relevance of the solution in the application domain (Hevner & Chatterjee, 2010 p. 9).

It is important to note that design science differentiates itself from the other approaches mentioned by Gregor (2006). The research project does not aim to further develop or test theories, neither does it try to determine the causal relationship between the critical factors involved in the identified problem. The research tries to contribute towards a solution for a practical problem with the created knowledge. The scientific community has furthermore highlighted the contribution of theory through design science, making it a mature field in this respect. Simon (1996) is a recognized advocate of design theory, while March and Smith (1995) propose design science as an activity to conduct research. Recent papers include (Gregor, 2006; Gregor & Hevner, 2013; Gregor & Jones, 2007; Hevner, 2007; Hevner et al., 2004; Kuechler & Vaishnavi, 2004, 2007, 2008).

Despite the field of design science literature becoming recognized and mature, little Design Science research has been performed (Peffers et al., 2006). This is partly due to the lack of a generally accepted approach in Information Systems (Peffers et al., 2006). It was when **Peffers et al. (2006, 2007)** with their introduction of the six-phase Design Science Research process model, that an explicit methodology was introduced to conduct design science research. The model builds upon other approaches and its activities (Problem identification, Objectives of a solution, Design and development, Demonstration, Evaluation, and Communication) are structured in a nominally sequential order. The model highlights the need for iteration and several research entry points to start the cycle and move towards a satisfying artifact (Peffers et al., 2006).

A paper by **Hevner et al. (2004)** was published in 2004, and further elaborated in 2007 by Hevner. In his work Hevner proposes a conceptual framework with clear guidelines to understand, execute and evaluate design science research. The framework consists of three spaces: Environment, IS Research, and Knowledge Base, and is occupied by three cycles of activities (Figure 3). **(1)** The Relevance cycle provides the requirements for the IS research and defines the acceptance criteria for the evaluation in the contextual envrionment, thus bridging the environment with IS Research. **(2)** The Design cycle iterates by generating design alternatives and evaluating the alternatives (against requirements), until a satisfying design is achieved. **(3)** The Rigor cycle bridges and informs the IS research with the knowledge base to make sure the designs produced are research contributions and not routine designs based on known processes (Hevner, 2007).

Verschuren and Hartog (2005) propose a six-stage design cycle to conduct design-oriented research (first hunch, requirements & assumptions, structural specifications, prototype, implementation, and evaluation). Although the model does not focus on the Information Systems discipline, it possesses several similarities (e.g. its focus on utility and satisfaction of the to be designed artifact towards the future user and other stakeholders) and is therefore also reviewed. The model of Verschuren and Hartog (2005) includes guidelines and evaluation criteria for each stage. The process starts by defining the goals of the research and ends in the evaluation of their achievement. In the occasion that the evaluation does not fully come up with the goals (or expectations and requirements of the stakeholders) the process starts a second run of the cycle and may start in the stage where the first run deficiencies occurred (Verschuren & Hartog, 2005).

Kuechler & Vaishnavi (2004) presented the Design Science Research Cycle to perform design science research, which builds upon the design cycle proposed by Takeda, Veerkamp and Yoshikawa (1990). The model links the flows of knowledge (knowledge contribution) with the research process steps (awareness of problem, suggestion, development, evaluation, conclusion) and the research outputs (proposal, tentative design, artifact, performance measures, results). The process is initiated with the awareness of a problem and emphasizes the problem-solving nature of design science research.

Sein et al. (2011) propose to compliment Design research with Action research and present an Action Design Research (ADR) method. They argue that the current design research approaches don't provide the required guidance and rigor needed to explicitly recognize artifacts as objects emerging from the design, use and ongoing refinement in its context (Sein et al., 2011). The two approaches share a common starting point and goals with design research. They are compatible and can inform each other (Hevner & Chatterjee, 2010 p. 192). The method purposively deals with the following two issues: (1) addressing a problem situation encountered in a specific organisational setting by intervening and evaluating, (2) constructing and evaluating an IT artifact that addresses the class of problems that are typical for the encountered situation.

After reviewing these design-science research frameworks, the three cyclic model of Hevner et al. was selected as a guideline for the research , complemented with Peffers et al. (2007) design science research procedure. The reasoning behind the first choice is that the framework of Hevner et al. helps to illustrate the research environments and the many iterations to be considered to achieve relevance and rigor within the research. The framework presented by Hevner et al. does not propose a process for performing design science research, unlike the other frameworks. However, the framework helps to assure the research's relevance by iterating with the application domain and making sure that the business needs are addressed. This practice oriented research project aims to solve the problem identified in the application domain (Section 1.2) and thus the framework better helps to identify and evaluate how the environment can be improved. It does so by iteratively constructing, evaluating and refining artifacts to swiftly reach a satisfactory design, while ensures innovation by incorporating prior and existing knowledge (Hevner & Chatterjee, 2010 p. 16).

As for the second choice Peffers et al. (2007) design science research procedure was selected, because it introduces an explicit methodology to conduct design science research consistent with prior literature (e.g. Hevner). The methodology of Peffers et al. is very similar to the one presented by Kuechler & Vaishnavi (2004). The model differentiates itself by merging and breaking the phases and including the identification that the research can be initiated from a variety of contexts, contrary to Kuechler & Vaishnavi where the research process always starts from the identification of the problem. The two models complement each other by filling out each other's gaps. While the model of Hevner et al. does not present an actual process, Peffers et al's model fails to maintain relevance. This could either lead to **(1)** a solution that can solve the problem, but not the one that the organisation was looking for. Or **(2)** research projects that take too long, because the model did not check whether the solution was "good enough" for the problem owner.

The model presented by Peffers et al. presents the stages of design science research (Section 2.3) and Hevner's three cyclic model illustrates the activities present within these stages (together with the guidelines to maintain rigor and relevance while performing the activities). The iterations in the model presented by Peffers et al. help to cycle between stages until rigor and relevance is obtained and align with the key activities proposed by the model of Hevner et al. (Section 2.2).

Other methods such as the design cycle proposed by Verschuren and Hartog (2005) remain somewhat unclear and don't illustrate how knowledge can be created. The model of Vershuren and Hartog (2005) possesses a vague entry point, consisting of a first hunch for constructing a new artifact. The framework is developed for design oriented research, however differentiates itself from design-science partly. This is due to its focus on satisfying the developer and stakeholders by fulfilling the research goals and meeting the requirements, neglecting the importance of knowledge contribution and sharing the knowledge obtained, as well as the problem-solving nature of Design-Science research.

The methodology introduced by Sein et al. (2011) develops an IT artifact through the iterative process of design, implementation, and evaluation in the specific organisational context where the problem occurs. The organisational intervention lies at the core of the ADR approach. The method requires the actual intervention of the developed artifact and thus goes beyond the scope of the research, whereas only the design principles are to be evaluated through interviews. General practice within Design science research is that the process calls for an intervention. The output of design science research must be studied and evaluated in the application domain (intervention) by methods such as action research (Cole, Purao, Rossi, & Sein, 2005).

2.2 Design Science Research Cycles

Information Systems Design Science Research aims to design artifacts that use Information Technology (IT) and are applied to organisations and society in general, rather than produce theoretical knowledge as in natural sciences (March & Smith, 1995). However as Lee emphasises (2000), technology and behaviour are not dichotomous in an Information System. They are inseparable, and similarly inseparable in IS research. "The truth (justified theory) and utility (artifacts) are two sides of the same coin and scientific research must be evaluated considering its practical implications, i.e. the practical relevance of the research result must be equally valuated with the rigor of the research performed to achieve the result" (Hevner & Chatterjee, 2010).

To achieve this, Hevner and his co-workers (2004, 2007) proposed a Design Science framework for IS research (Figure 3). The methodology includes the following seven guidelines, which also served as guidelines in this research project. (1) Design science research must produce a viable artifact in the form of a method, model, construct or an instantiation. (2) The research problem should be relevant and therefore the objective of design science research ought to be the development of solutions to important and relevant business problems. (3) The design artifact must be rigorously demonstrated through evaluation methods. (4) Design science research must provide clear and verifiable contributions to be effective. (5) The research must apply rigorous methods in both the construction and evaluation of the design artifact. (6) The design process is a search process, where available means are used to reach desired ends while satisfying the problem environment. (7) The design science research must be communicated and presented to technology- and management-oriented audiences. In the framework introduced by Hevner and his co-workers (Figure 3), the environment represents the problem space. In IS research it consists of people, organisational systems and their existing or planned technological systems. It entails the goals, problems, and opportunities that define business needs as they are perceived by the people within the organisation. The framework helps to frame the research activities in a way that the business needs are addressed and defines acceptance criteria for the artifact evaluation assuring the research's relevance (Hevner et al., 2004). The output of the design research must be placed in the application domain for study and evaluation. This process determines if additional iterations of the relevance cycle are needed in the design research project.

The knowledge base provides the foundations and methodologies through which IS research is accomplished. Prior IS research and results provide theories, frameworks, constructs, instruments, models and methods used in the development phase of a research study. Rigor is achieved by applying existing foundations and methodologies in a suitable manner for the specific context.

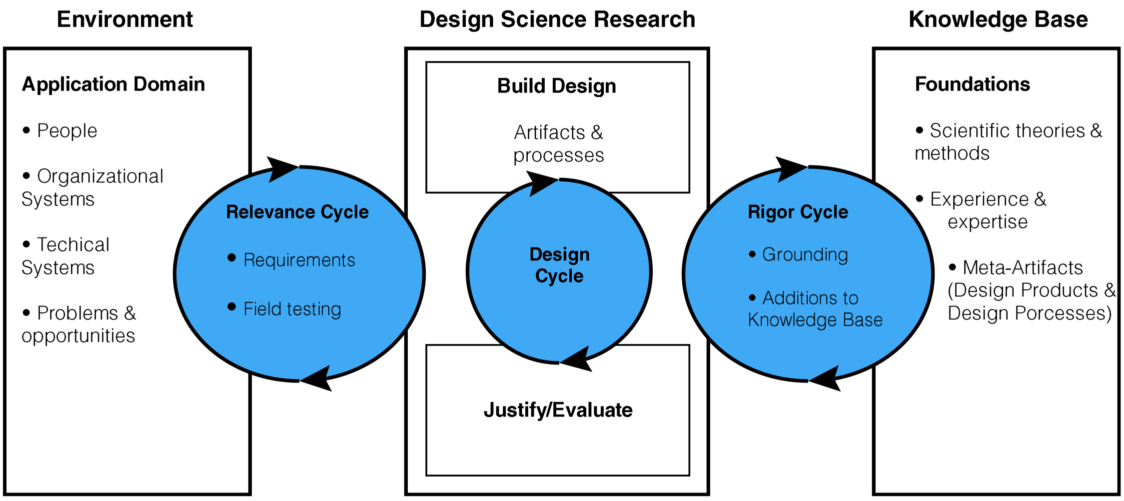


Figure 3 Information Systems Design Science Research Framework by Hevner et al. (2004)

2.3 Research Design Process

Peffers et al. (2007) propose a sequential six-phase Design Science Research process, as is displayed in Figure 4. This process is the accumulation of concepts in prior literature about design science in information systems. Although the process is presented in a linear manner, the process has several entry points to start the research and highlights the importance of iterations. Based on the evaluation, the researcher can decide whether to iterate back to the first activities to try and improve the artifact or to continue and communicate the findings (Peffers et al., 2007). This research project is problem-centred (Section 1.2). The development of the sub-objective will follow the full six steps, while the research objective will skip the demonstration and evaluation phase for future research (Section 1.3).

The process (Figure 4) revolves around the following six activities.

1. Problem identification and motivation. The first activity identifies the specific research problem and the value of a solution. The activity requires knowledge of the state of the problem and the importance of its solution.

2. Define the objectives for a solution. The second activity revolves around transforming the problem into requirements. Describing how a new artifact is expected to support solutions to the problems addressed. The activity requires knowledge of the state of the problem and the current solutions, if there are any, and their effectiveness.
3. Design and development. This activity involves the creation of the artifact (Table 1), including the determination of the artifact's desired functionality. The activity requires knowledge of theory that can be used in a solution.
4. Demonstration. The use of the artifact is demonstrated through a case study, simulation or other appropriate activity. The activity requires knowledge on how to use the artifact to solve the problem.
5. Evaluation. The evaluation involves observing and measuring how well the artifact supports a solution to the problem. The activity requires knowledge on the performance metrics to be used to analyse the effectiveness of the artifact.
6. Communication. At the end of the design process, the several research elements (i.e. the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness) are communicated to the research community and other relevant audiences.

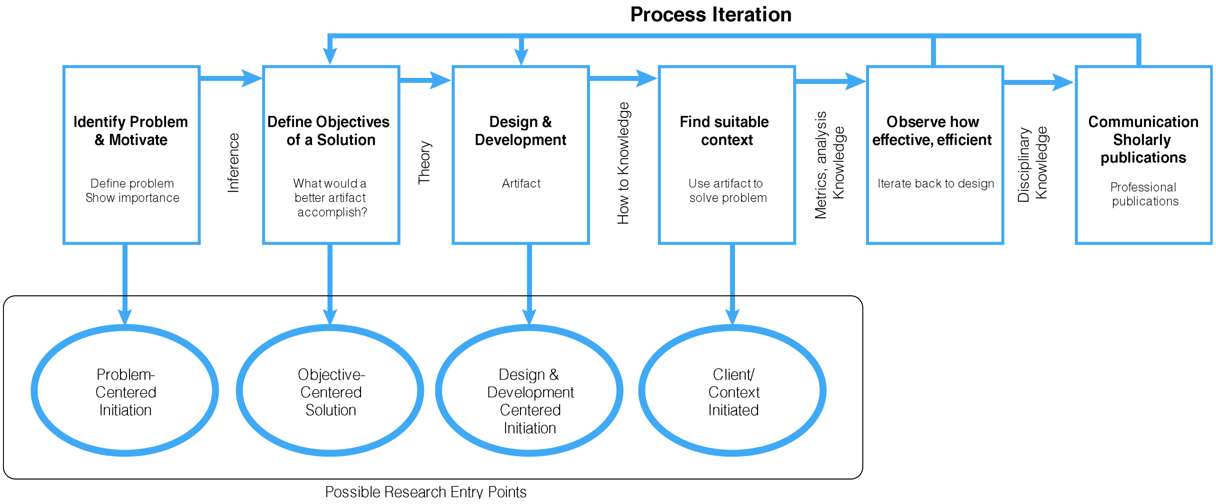


Figure 4 Design Science research procedure, as adopted from Peffers et al. (2007)

Several types of artifacts, which are the end-goal of any design science research project, are illustrated in Table 1. This research project aims to develop artifacts 3 and 5 (Section 1.5).

<table>
<tr><th></th><th>Output</th><th>Description</th><th colspan="2">Author</th></tr>
<tr><td>1</td><td>Constructs</td><td>The conceptual vocabulary of a domain that describe the problems and their solutions</td><td rowspan="8">(Kuechler & Vaishnavi, 2004), p.12</td><td rowspan="2">(March & Smith, 1995), p. 255</td></tr>
<tr><td>2</td><td>Models</td><td>Sets of propositions or statements expressing relationships between constructs</td></tr>
<tr><td>3</td><td>Frameworks</td><td>Real or conceptual guides to serve as support or guide</td><td rowspan="3"></td></tr>
<tr><td>4</td><td>Architectures</td><td>High level structures of systems</td></tr>
<tr><td>5</td><td>Design Principles</td><td>Core principles and concepts to guide design</td></tr>
<tr><td>6</td><td>Methods</td><td>Set of steps used to perform tasks – how-to knowledge</td><td rowspan="2">(March & Smith, 1995), p. 255</td></tr>
<tr><td>7</td><td>Instantiations</td><td>Realization of an artifact in its environment. They demonstrate the feasibility and effectiveness of the models and methods they contain</td></tr>
<tr><td>8</td><td>Design Theories</td><td>A prescriptive set of statements on how to do something to achieve a certain objective.</td><td></td></tr>
</table>

Table 1 Types of outputs in Design Science Research (Kuechler & Vaishnavi, 2004; March & Smith, 1995)

2.4 RESEARCH STRUCTURE

Subsequent to the model introduced by Peffers et al. in Figure 4, the research structure in its application presents itself as followed (Figure 5). The blue blocks indicate theoretical knowledge and information, derived from external sources based on literature reviews and case studies. The green blocks represent products produced by the researcher, while the red blocks exist of knowledge and information obtained from the application domain.

The blue blocks represent the data derived from desk research on the theories of importance. The theory of innovation portfolio management (IPM) was chosen to fully understand the IPM process (i.e. the variety of methods, the input and output criteria and practical implications). The theories on innovation management is needed to help integrate the IPM process within the innovation management practices and understand how information and knowledge is transferred between these two processes. The theories on decision making and decision-support systems is needed to understand the complexity of the decision-making process and how the process can be improved (i.e. made more more visible, structured and faster). Following several interviews and workshops, 'additional theory' (on methodologies, models and systems) might get brought forth and are analysed and joined with the theoretical framework to create an enriched framework (Figure 5). The enriched framework serves as the input for the artifact development process (activity 3, Figure 4) and as a basis for the design requirements of the IPM tool first viable product (FVP) and innovation support framework (Sections 1.3 & 1.5). The design of the IPM tool is iteratively demonstrated, evaluated and improved through case studies. The accumulation of the final design requirements for the IPM tool, the theoretical validation of the output from the case studies, and the assembled innovation support framework, results in an enriched design which serves as the output (artifacts) of this design science research (the deliverables, Section 1.5).

The theories will be further specified in the Theoretical perspective in Chapter 3. The red blocks, mainly consisting of data collected through interviews, meetings, case studies, workshops, and seminars, will be further elaborated in the Application domain in Chapter 4. The green blocks are the artifacts developed by means of this research and will be further discussed in the Design review in Chapter 5.

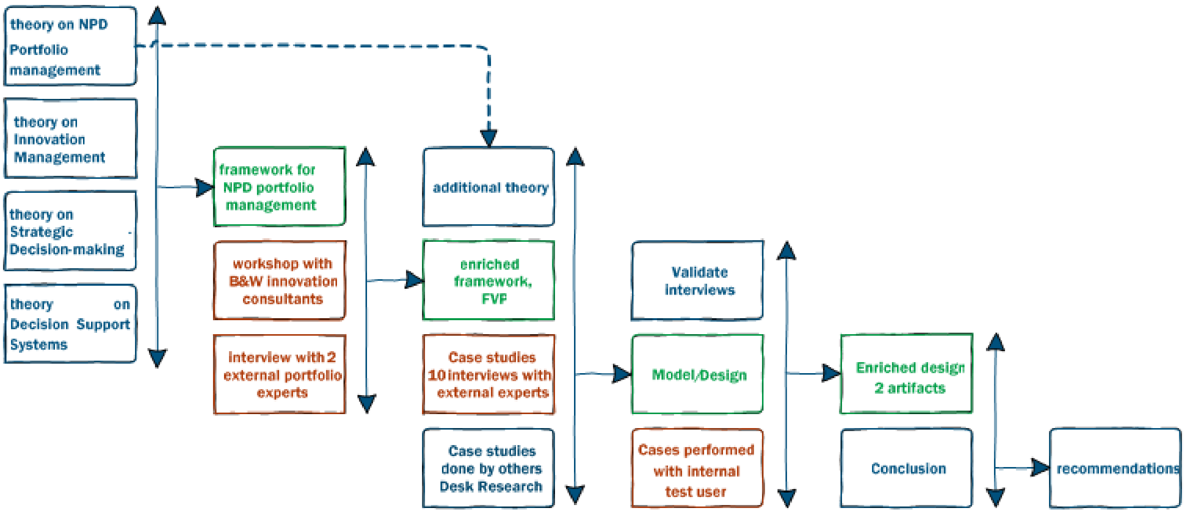


Figure 5 The roadmap of this Design Science research project

3 THEORETICAL PERSPECTIVE

This Chapter introduces and reviews the main theoretical perspectives that need to be considered to develop the artifacts envisioned. The Chapter helps to identify the models that can be considered as a basis for the innovation support framework, the characteristics of the innovation portfolio management process that need to be considered for the innovation portfolio model, and the relation of innovation portfolio management with other innovation management practices to create the right synergy. Seeing how important external sources of knowledge are in the innovation process (Sections 3.1.2 & 3.4.3), it is important to identify how external linkages can be incorporated into the artifacts (Section 1.5) to make the models utilise external data and knowledge. The existing knowledge base and its appropriate application help to achieve rigor in the research.

The output of this Chapter is used in the next Chapter (Application Domain) to better understand the organisational problem at hand, how the current solutions in the application domain relate to the existing knowledge base, and make sure that the business needs are addressed to achieve relevance in the application domain.

The Chapter answers the following questions:

> *SRQ1: Which theories are linked to an Innovation Portfolio Management decision support system, capable of adapting to the user's context and integrating with the user's current innovation practices?*

> *SRQ2: What are the requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?*

The Chapter starts by defining innovation (Section 3.1.1), how innovation models have evolved (Section 3.1.2), moving on to explain the different ways innovation can be managed (Section 3.2), what innovation portfolio management is (Section 3.3), and then concludes the Chapter by making clear what the role of the decision-making process in innovation management is (Section 3.4). The Sections end with the **design requirements** obtained from the theories discussed.

3.1 INNOVATION MODELS

Real success in innovation lies in the ability of repeating the trick, i.e. being able to innovate successfully repeatedly. This requires that the process is managed consistently so that success, whilst never guaranteed, is more likely and little gets left to chance (Tidd, Bessant, & Pavitt, 1997 p.13). To help structure the innovation process, innovation management models and practices need to be studied. Innovation management practices act as a means to codify and apply innovation research and helps to study innovation success (Tidd & Thuriaux-Alemán, 2016).

3.1.1 INNOVATION

Innovation is a very broad concept. It is often interchanged with the concept of "invention". An invention, however, is the conception of the idea, whereas innovation is the translation of the invention into the economy. The invention is only a small part of an innovation. Considering this, a slightly adapted version of the definition, introduced by Trott (2012 p.15), will be used for this research: "Innovation is the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product, process or service". Innovation itself is a management process and can only succeed if properly managed. Innovation comes in many forms, such as product, process, service. Innovation and product development in this paper refers to any of these many forms.

3.1.2 THE EVOLUTION OF INNOVATION

The way companies innovate has seen some changes. Various scholars have identified different numbers of generations. Rothwell (1994) distinguishes five generations, while Miller (2001), Niosi (1999), and Ortt & Duin (2008), identify four generations, and Cooper (1994) three. While there is some variation regarding the timing of the various generations, there is a consensus on the models of the first three generations.

Traditionally, the innovation process was viewed as a sequence of separable stages or activities. This linear model of science and innovation dominated the industrial policy after the Second World War. They are linear, because innovations are assumed to pass through a well-defined set of stages. The first innovation model was technology-driven (also known as "technology push" or "first generation"), where scientists would make unexpected discoveries and linearly progress towards the marketplace. Little attention was paid to the role of the market place and the innovation processes served no strategic coals (Ortt & Van Der Duin, 2008). The simplified model can be seen in Figure 6.

Figure 6 Technology Push innovation model (Trott, 2012)

In the second half of the 1960s, the focus shifted from technology to the identification of market needs because of increased competition (Rothwell, 1994). The marketplace started to play an important role in the innovation process. This led to the development of the second linear model, the customer need-driven model (also known as "market pull" or "second generation") (Ortt & Van Der Duin, 2008; Trott, 2012). Technological change is rationalized and the customer needs are considered more important. The innovation process would neglect long-term programs and focusses on customer needs, therefore leading to "incrementalism". The innovation process would linearly progress, starting with the market need (Ortt & Van Der Duin, 2008), as illustrated in Figure 7.

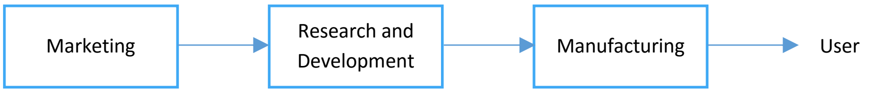


Figure 7 Market Pull innovation model (Trott, 2012)

Late 1970s to the early 1990s was characterized by a period of inflation, oil crises, and demand saturation. Supply would exceed demand resulting in high unemployment (Ortt & Van Der Duin, 2008). This resulted in the combination of market-orientation and technology-focus (also known as the "coupling model" or "third generation"). Innovations were initiated through close interactions with customers to avoid any unnecessary costs (Von Hippel, 1978). Company strategies were generally focussed on cost control and reduction. A study of Von Hippel (1976) argued that if a firm only follows the technology content, it will in effect develop something that the user might not want or need. Subsequently, if a firm only utilizes the user need, it will in effect only know what the user needs, but might lack the technology to build a suitable device. A firm, therefore, must utilize both information. Organisations adapted towards this approach and became more flexible and less hierarchically organized, introducing the first feedback loops in the model as can be seen in Figure 8.

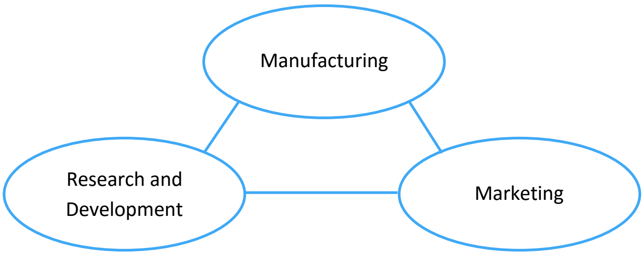


Figure 8 The Simultaneous coupling innovation model (Trott, 2012)

For the next generation of models, the focus will be on the changes and evolutions that occurred in how the innovation process was viewed. It was in the 1970s and 1980s that Abernathy and Utterback (1978) and Foster (1986) argued that technological advancement was dependent on the effort put into the development of the technology. The introduction of a new technology would cause a reaction from competitors resulting in a more important role of the competition in the innovation process. Organisations possess certain routines and capabilities that are relatively fixed (or slow to change) and thus to some degree grow and die with those capabilities. These cycles take the form of the "product life cycle" (PLC) and is associated with growth S-curves (Figure 9). Under normal circumstances, technological progress starts off slowly and then increases rapidly to then finally diminishes as the technology limits are approached. This is referred to as an S-curve. At the end of the S-curve a new technology replaces the existing one (Foster, 1986).

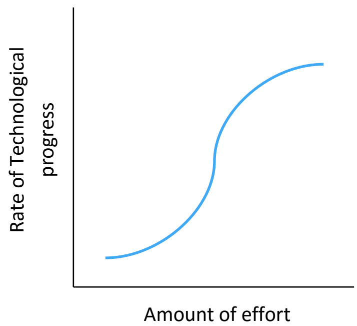


Figure 9 The technology S-curve (Trott, 2012)

Once a technology radical innovation enters the market, it can cause a disruption and change the rules of the game in the competition. These innovations are called "disruptive innovations" (Christensen, 2013), this concept was referred to by Schumpeter as "creative destruction" (Schumpeter, 2013).

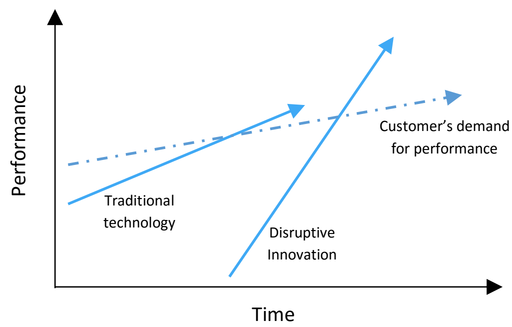


Figure 10 Disruptive innovations & the innovator's dilemma (Trott, 2012)

Disruptive innovations change the landscape in a discontinuous manner (see Figure 10). Companies that neglect new technologies and niches that, in the short run, are not competitive in the main market and relied too much on incremental innovations, face the risk of getting "locked-in". Large firms were too driven on large opportunities and are pushed by their sense of relevance and incentives leading the incumbent becoming unaware of small startups that had enough incentive to pursue the niche. The technical progress in the niche may be faster than in the main market, and the time might come when the niche technology is 'good enough' for the main market and maybe even superior on some new dimension, leading to a take-over of the main market by the niche technology. This phenomena was introduced by Christensen (2013) and is called the 'Innovator's Dilemma'. Technological progress would be the result of a discontinuity of technologies only to be replaced by newer ones that perform better or better meet the customer needs Figure 11.

Developing new technologies, may allow an established company to bring a product to the market that its most profitable customer cannot use. This new product may also turn up to be unprofitable relatively to the other options in the organisation's innovation portfolio. For these reasons, organisations usually find it difficult to embrace the opportunities of a new technology. The new technological progress often outdoes the ability of the customer to absorb the new technology. The development should be put on hold. "As the technology rapidly improves, eventually it will intersect with the customer needs. When that happens, it would become disruptive and destructive to the leading firms in the industry that are based on the old technology" (Christensen, 2013).

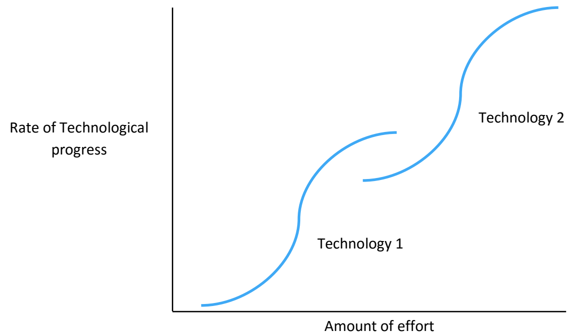


Figure 11 Technology life cycles and S-curves (Trott, 2012)

Innovation models started to shift towards the need to share and exchange knowledge and this resulted in the innovation "network models", also known as the "fourth generation" innovation models to many authors (Berkhout, Hartmann, Duin, & Ortt, 2006; Chesbrough, 2003a; Christensen & Raynor, 2013; Niosi, 1999). Traditionally large firms would rely on their internal R&D to create new products. The internal R&D was a strategic asset and served as an entry barrier for potential rivals (Figure 12). Firms would outperform smaller rivals in the process by possessing strong R&D capabilities (Teece, 1986). Although this "closed innovation model" has worked good in the past, the cost of building and sustaining the necessary technical expertise and special equipment is rising dramatically.

Even large corporations cannot maintain their leadership in some market segments they traditionally dominated. Firms acquire external technology and knowledge by means of strategic alliances with external parties and sharing their skills and resources. These changes have given rise in more benefits for firms to open up their innovation process (Chesbrough, Vanhaverbeke, & West, 2014 p.19).

The academic community started noting that firms should be more open to outside information and knowledge. It was not until Chesbrough and Rosenbloom (2002) started studying the commercialization of Xerox PARC inventions by spinoff companies, that the term and model of Open Innovation was presented (Chesbrough, 2003a). This open innovation model promoted the use of external ideas and knowledge and places an emphasis on the new knowledge-based economy (Figure 13). Knowledge flows across the boundaries of an organisation, leading to in-bound and out-bound innovation. “It is the use of cheap and instant information flows that place even more emphasis on the linkages and relationships of firms. The landscape has changed to one where firms must ensure that they possess the capability to fully capture and utilise ideas from these linkages” (Chesbrough, 2003a).

It is undoubtedly that Chesbrough brought the approach of open innovation to a wide audience, however, the concept of utilising external knowledge in the innovation process is not new. Trott & Hartmann (2009) argue that the open innovation paradigm is not a new one and has been visible in earlier periods. Innovation scholars had the understanding, since the 1970s, that sources of innovative ideas often came from outside the firm (Von Hippel, 1978).

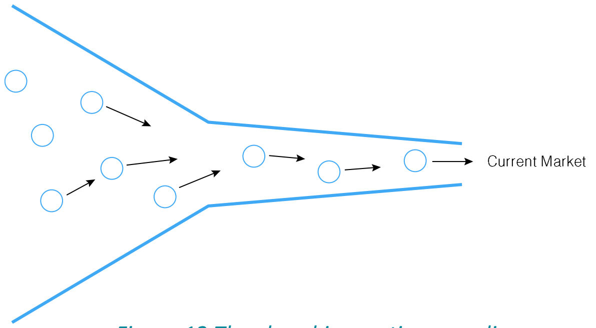


Figure 12 The closed innovation paradigm (Chesbrough, 2003b)

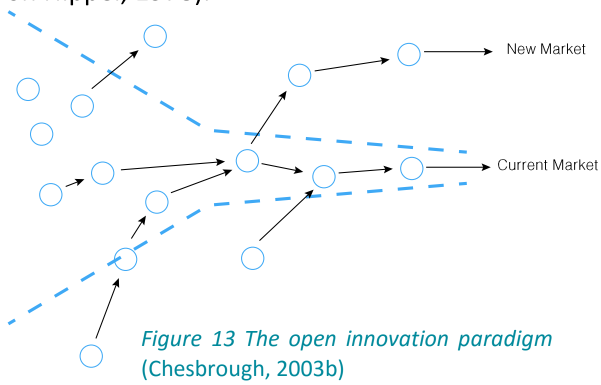


Figure 13 The open innovation paradigm (Chesbrough, 2003b)

Opening-up the innovation process does not suit all industries or companies and might even endanger fundamental research, which is the basis for innovation in many cases. “In certain industries, the internally focussed approach to R&D remains well suited for managing innovation” (H. W. Chesbrough, 2003 p.34). As Ortt & Van Der Duin (2008) argue, “firms adapt their innovation approach to their internal and external environment and other contextual factors”. E.g. business-product companies tend to place heavier emphasis on finding new uses or market for their products, while consumer-product companies focus more on totally new products and product positioning. These contextual factors require different innovation management practices (Hanna, Ayers, Ridnour, & Gordon, 1995).

Illustrated in Figure 11 are the technology life cycles and s-curves following each-other. As Christensen (2013) and Schumpeter (2013) argue, new disruptive innovations are always around the corner and will take over and disrupt existing technology. Technology builds on technology and this is how a better performing technology comes into creation. This continuous view of the innovation process is shared by the authors promoting the Cyclic Innovation Model (CIM) (Berkhout et al., 2006). As mentioned earlier in this Section, most innovation models view innovation as a linear process from R&D to marketing. The problem with this view is that it ignores the many feedback loops that occur between the various stages of the process. These models focus on what is driving the downstream efforts rather than on how innovations occur. The overall innovation process can be viewed as a complex set of communication paths, existing of internal and external linkages, whereby knowledge is transferred. Success lies in the ability of the firm to acquire and utilize knowledge and apply this to the development of new products. The CIM model illustrates how knowledge is combined with entrepreneurship to develop new ventures. Linkages to the marketplace can lead to new innovations and society can inform organisations of their needs leading to new products and services. “Knowledge therefore is technical *and* social and the linkages work in two-ways” (Berkhout, Hartmann, & Trott, 2011).

The upper half of the CIM model, shown in Figure 14, is where technological development takes place and technological research plays a central role. Technological research is driven by cyclic interaction between new scientific discoveries and technical specifications for new-product combinations. In the sciences cycle (left side of Figure 14), technological research is driven by new scientific insights (science push), and in the engineering cycle (right side of Figure 14), technological research is driven by new functional requirements in product development (function pull). Scientists and engineers must constantly inspire each other and so research must be organized in such a way that no barriers exist between the two cycles.

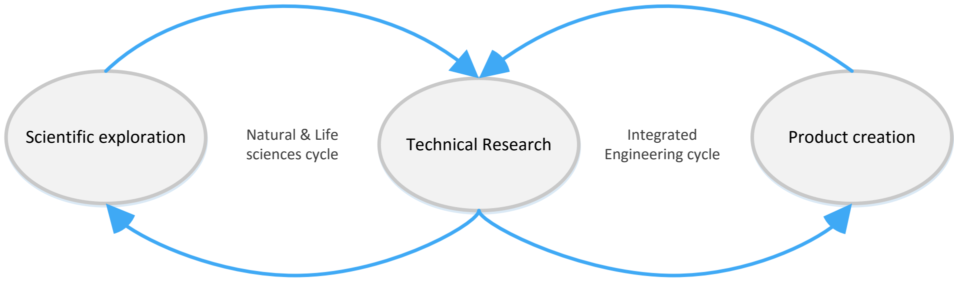


Figure 14 The information and knowledge linkages surrounding technological research (Berkhout et al., 2006)

The lower half of the model, shown in Figure 15, visualizes the dynamics around the market transitions. It is not the technology that plays a central role, but the market. In the soft sciences cycle (left side of Figure 15), the cyclic interaction facilitates the development of new (predictive) insights into rising and falling (market) transitions. Market transitions are viewed as a dynamic process in which the changing demand for product-service combinations is determined by the dynamics of society’s needs and concerns. In the differentiated services cycle (right side of Figure 15) new product-service combinations are used to address changing markets at the appropriate time. In this cycle, market transitions are a dynamic commercial process in which the capability of businesses to innovate determines the changing supply of product-service combinations. In an innovation economy, “it is important that scientific insights (left-hand side of Figure 15) into changing demand and business investments in a changing supply (right-hand side of Figure 15) must continuously inspire and strengthen each other” (Berkhout et al., 2011).

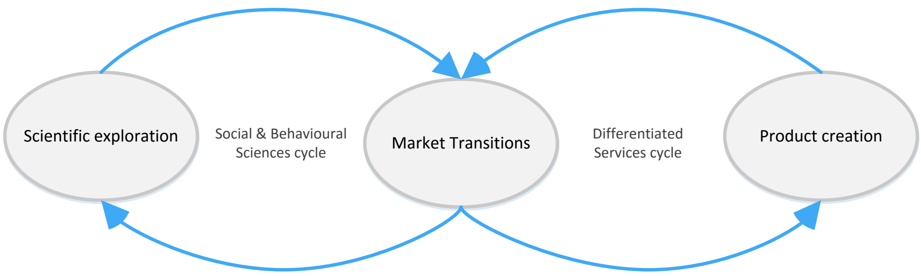


Figure 15 The information and knowledge linkages surrounding market transitions (Berkhout et al., 2006)

The full CIM model (Figure 16) reflects the continuity of the innovation process in a circular way along four nodes. These four nodes are: technological research, scientific exploration, market transitions and product creation. This model architecture shows that innovation is not a chain but a circle and innovation does not have a fixed starting point. New ideas may start anywhere in the circle, triggered by a change in the four nodes. These dimensions interact consistently, leading to the accumulation of value creation. “Innovations build on innovations. Ideas create new concepts, successes create new challenges, and failures create new insights” (Berkhout et al., 2006). The entrepreneur is placed in the centre and needs to interact directly with all disciplines to manage and govern the process. Innovation may start anywhere on the circle, but even though innovations may originate in any of the four basic cycles of the innovation cycle, the involvement of the other cycles is indispensable. Only modifications and improvements can arise from a single cycle. A shared framework is essential to create synergy between the diverse players in the innovation arena.

The model illustrates the many information and knowledge exchanges that occur in the innovation process, including the diverse innovation stakeholders and their relations. The framework does not support managing innovation projects, since it sees innovation as a continuous process that always occurs. Nonetheless, it illustrates the many relevant knowledge exchanges, and could act as an effective communication instrument by connecting experts from different organisations and different disciplines, as will be further illustrated in Section 5.5.

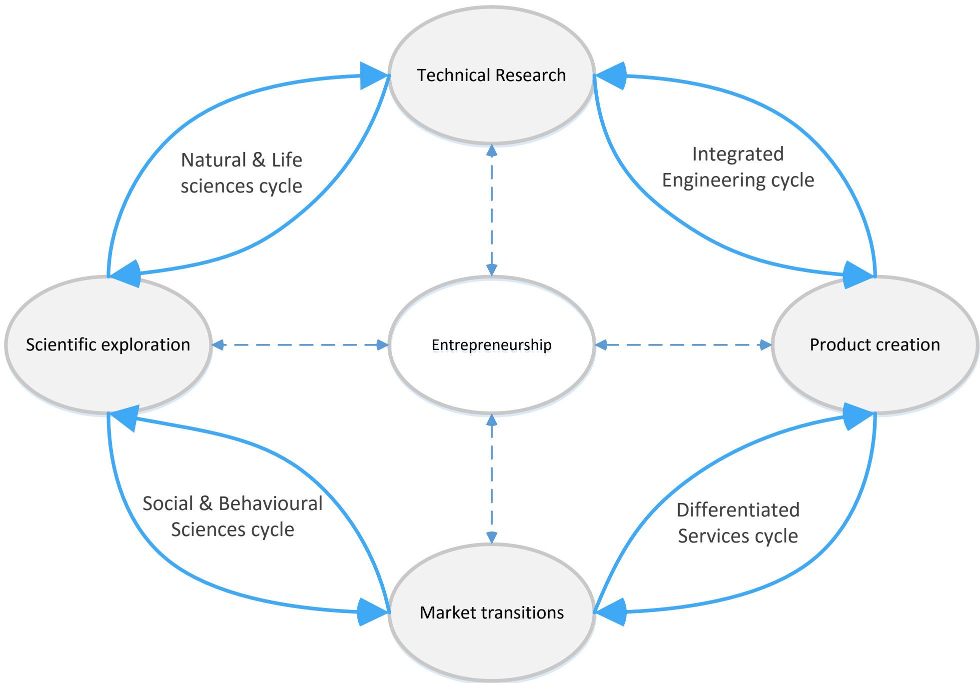


Figure 16 The Cyclic Innovation Model by Berkhout, Hartmann, & Trott (2010)

The importance of including potential users in the development is highlighted by several authors. User innovation refers to innovation by intermediate users (e.g. firms) or consumer users (e.g. end-users), rather than by suppliers, producers or manufacturers (Bogers, Afuah, & Bastian, 2010). In the 1960s several studies showed that user firms were responsible for many minor technical improvements (Freeman et al., 1968; Hollander, 1965). Several authors argued that users can develop and introduce both minor improvements as well as more radical breakthrough innovations. It was von Hippel’s research, that first explicitly paid attention to the central role of users as innovators (Bogers et al., 2010; Von Hippel, 1976). Eric von Hippel observed that many products and services were actually the result of refinements and developments by users (Von Hippel, 1986). Most products were developed to meet the widest possible of needs, which left individual consumers, that face problems other than those of most consumers, with no other possibility than to develop their own modifications to existing products. Von Hippel introduced the lead-user method that can be used to learn about user innovation in a systematic manner and incorporate their refinements and insights in the innovation process. The methodology implies to incorporate lead-users in the concept generation, testing phase, pre-market forecasting as well as post-launch as opinion leaders to identify important modifications and improvements (Urban & Von Hippel, 1988).

To develop successful products, user needs must be accurately understood. The task, however, is becoming steadily more difficult as user needs change more rapidly. Von Hippel (2001) proposes the development of toolkits, to provide users with the ability to participate in the product development. User toolkits for innovation allow developers to abandon their attempts to understand user needs in detail, for the transfer of need-related aspects of product development to users along with an appropriate toolkit. The toolkits can be used to customize physical products or services that are then produced by a manufacturer or directly at the user's location. The user toolkits are specific to given products and to a specified production system. They provide users real freedom develop their custom product through iterative trial-and-error. The toolkits allow users to create a preliminary design, simulate or prototype it, evaluate its functioning in their own use environment, and then iteratively improve it until satisfied (Von Hippel, 2001).

This section illustrated how some organisations prefer to innovate internally in a closed manner (secrecy) and others utilise external knowledge and possess a more 'open' approach towards innovation. Organisations could also adopt an internal and externally innovation approach simultaneously (dual approach). One of the biggest oil- and gas-companies, Shell, serves as a good example. Shell has one main mission, and that is to provide energy. To be able to remain doing this Shell needs to be able to adapt fast to the rapidly changing environment. This is why Shell adopts a dual approach (Verloop, 2006). On one hand, it innovates incrementally in the traditional oil and gas industry, while at the same time it focusses on radical innovations in new energy markets (e.g. the 2nd Borssele windfarm, at the time, was the world's cheapest offshore wind farm). While the incremental innovations are developed in-house, the radical ones are developed in collaboration with partners, e.g. Game Changer (Shell, 2017). The question then remains; does Shell use different innovation models? Yes and no. If innovation begins with scientific research and progresses linearly via technological and product development to marketing. Following the previous models of innovation (innovating internally or openly), these are different models. In these innovation approaches Shell takes on the role of the entrepreneur, the role of this individual or team is not captured in linear models. However, ideas or concepts don't always originate from the entrepreneur, the entrepreneur might not even market the product (like in the cases of Game Changer). According to Berkhout, Hartmann & Trott (2010) "innovation serves as an information-creation process that arises out of social interaction that provide the opportunity for thoughts and views to be shared and exchanged". When changes occur in one or more of four areas; technological research, scientific exploration, market transitions and product creation, it can lead to a wealth of business opportunities. Here, the entrepreneur (i.e. Shell) plays a central role: by making use of those opportunities. "Without the drive of the entrepreneur there is no innovation, and without innovation there is no new business" (Berkhout et al., 2011).

3.2 Innovation Management

3.2.1 Innovation model classification

Following the evolution of innovation models from management literature in the previous Section, numerous management models are classified into several distinct categories. The first two categories represent the early form of innovation models: *departmental-stage models* and *activity-stage models*. These linear models are also referred to as “over-the-wall” models, where each department in an organisation is responsible for certain tasks (Trott, 2012 p.438). Departments would carry out their tasks before throwing the project ‘over the wall’ on to the next department. What differentiates the activity-stage models from the departmental ones, is the emphasis on activities that better represent how the process looks like in reality. Activity-stage models also facilitate the iteration of activities using feedback loops. Several authors have criticized the models, because they believe the models would hinder the innovation process. The first model neglects the reworking and consultations between functions and the continual input from market research, while the second model does not allow for the simultaneous performance of activities (Trott, 2012 p.438). The critics (such as Lorenz, 1986) highlight the importance of cross-functional approaches and the issues that come along with ambiguity and a lack of communication. Thus, the need for dedicated project teams was introduced.

Recognizing the common problems around the cross-departmental communication that occur within the innovation process, lead to the development of the *cross-functional models (CFT)*. Projects would frequently be passed back and forth between functions, resulting in the lengthening of the innovation process. The use of cross-functional models helps to solve these issues by deploying dedicated project teams representing people from a variety of functions.

Authors such as Cooper and Kleinschmidt (1990; 1993) proposed a different view of innovation that perceives it as a process revolving around a series of decisions that need to be taken in order to progress the project. These so-called *decision-stage models* revolve around multi-functional teams that need to successfully complete a prescribed set of cross-functional tasks in each stage to obtain management approval so that they can proceed to the next stage of the innovation process.

The final classification represents the most recent view of the innovation process. These *network models* highlight the importance of the accumulation of knowledge from various sources and emphasise the external linkages coupled with the internal activities. The models build further on the notion of a knowledge economy and suggest that external linkages can enhance the innovation process by facilitating additional knowledge flows into the organisation. The innovation process should be viewed as a knowledge-accumulation process with inputs from a variety of sources.

Most innovation literature present the innovation process as an eight-phase linear model (Table 2). The model starts with an ideation process, where new ideas are generated, and ends shortly after the commercialisation. The reason for this simple perception is that the process is often viewed from a financial perspective, where cash outflows precede cash inflows. These linear models are widely adopted and dominate the innovation process management for their simplicity, but they do not reflect reality. More recent research suggests that the innovation process should be viewed as a simultaneous and continuous process with cross-functional interaction (Barczak et al., 2009; Berkhout et al., 2006). However, when it comes to managing the innovation process within the firm, the gating-approach

(Section 3.2.2) dominates practice. This is because the project management advantages tend to outweigh the limitations it poses to the innovation process. In practice, the central position in the innovation process is often occupied by a manager who adopts a stage-gate approach and culture rather than an entrepreneur (Berkhout et al., 2010). Section 3.1.2, also argued that the continuous and simultaneous view of the CIM model would provide difficulty for the innovation manager. This is because the model does not provide the ability to map an innovation in time, does not illustrate the relevant activities, deliverables and doesn't allow for the early termination of "bad" projects.
The following Section further illustrates the stage-gate approach (Cooper, 1990), and how the model has evolved over the last three decades.

1	Idea generation
2	Idea screening
3	Concept testing
4	Business analysis
5	Product development
6	Test marketing
7	Commercialisation
8	Monitoring and evaluation

Table 2 Common linear innovation model adopted from (Trott, 2012 p.433)

3.2.2 THE STAGE-GATE PROCESS

The Stage-Gate process has many variations. It is also called the new product process, gating process or phase-re-view process. This is the formal process that firms use to drive an innovation from idea to launch (Cooper, 1990). Multi-disciplinary teams must successfully complete a prescribed set of cross-functional tasks in each stage before obtaining a "GO" from the management to cross the decision gate and proceed to the next stage of the product development. Figure 17 illustrates the steps in the process.

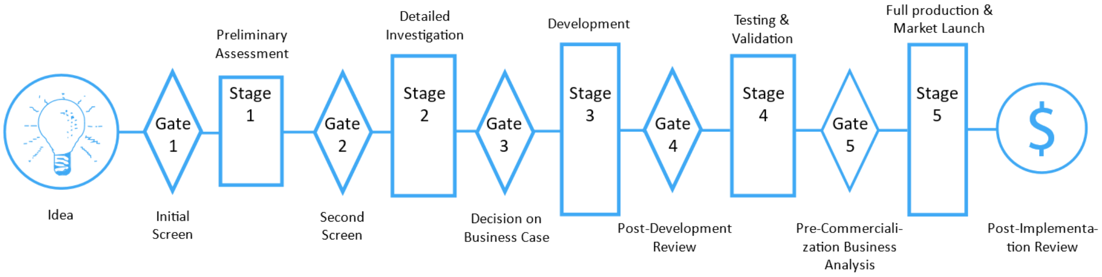


Figure 17 The Stage-Gate innovation process (Cooper, 1990)

The Stage-Gate starts at a later point in the innovation process, when an idea is already selected to be evaluated for its potential success. It lacks a strategy on how to receive, perceive and manage these ideas. Not all ideas can be led through the Stage-Gate, assuming it would take a lot of resources to do so. This is not the only limitation, the Stage-Gate process in its first form (Cooper, 1990) suffered from several limitations. Among them; the process being sequential and slow, focussing on the end gates rather than on the customers, innovation concepts can be stopped too early, a low level of knowledge held by the gatekeeper can lead to poor judgements being made on the project.

Over the years, organisations and Cooper have modified and adapted the Stage-Gate model to better serve current innovation practices. When first implemented, there was only one version of the Stage-Gate. And the rule was one size fits all. Companies have adjusted and created a version tailored to their specific innovation process. Over the years, Cooper has researched these best practices of the Stage-Gate process and taken some effort in improving the model, by providing more flexible and agile options (Cooper, 2008, 2014a). This has been done by making the Stage-Gate scalable (Appendix E: Stage-Gate development). The changes allow for a better fit with the business needs to accelerate projects by reducing the number of gates. The higher the risk, the more one adheres to the full five-stage process. Another important change is the development of spiral feedback loops for test and customer feedback to be incorporated into the design. These changes have resulted in "The Next Generation Idea-to-Launch System" shown in Figure 18. This model allows innovation managers to move forward, without having to wait for perfect information. It is acceptable to move from one stage to an earlier one, and thus, overlap stages. The model also includes an additional stage: the generation of ideas.

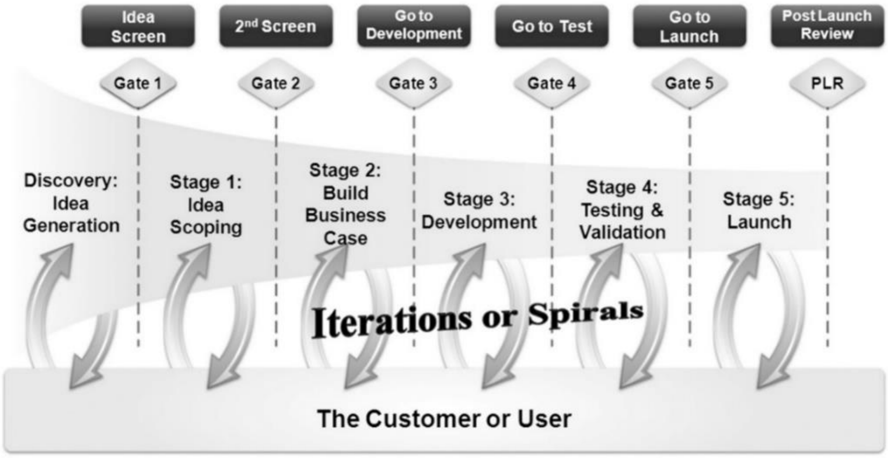


Figure 18 The Next-Generation Idea-to-Launch System (Cooper, 2014)

This new, more agile and flexible model does not seem agile enough when compared to other models, such as the CIM model (Sections 3.1.2). The model lacks in the following areas among others. **(1)** Changes occurring in the external environment do not influence the process, e.g. a change in the innovation portfolio does not influence the idea scoping. The idea/project is evaluated individually. **(2)** Another important element is the adaptability to external requirements. The model allows for spirals and iterations with customers and users, but the importance of other innovation stakeholders (such as universities, suppliers, partners, and other stakeholders) are not highlighted. **(3)** Market transitions and trends will only come to light at the gates, once a decision must be made, leading to insufficient or too many resources being allocated to the project. **(4)** The model does not allow skipping a or moving back a couple of stages based on the iterations (e.g. once a customer changed his needs during the validation, this would mean the termination of the project and start of a new project, which is not efficient and costly). There are no feedback loops, i.e. the model assumes that innovation is a linear process that always progresses from idea to market introduction, rather than giving insights in the dynamics of the actual innovation process. **(5)** This model also assumes that every project is a product on its own and does not have any links to previous similar products, while innovation is a continuous cyclic process and the starting point of innovation could be anywhere in the innovation cycle. This would result in additional resource spending, such as on the identification of relevant stakeholders and "re-invention of the wheel" (i.e. neglecting relevant previous insights, learning, and start from scratch).

The Stage-Gate process reviews the potential success of innovation projects individually and fails to review the linkages between the ideas and projects. The idea management process, i.e. ideation and idea screening (stage 1 & gate 1 of the Stage-Gate process), must therefore be separated from the Stage-Gate's project management methodology. The ideation process involves the generation, development and facilitation of new ideas. The idea management process provides the ability to capture feedback or insights from internal and external stakeholders to utilise this feedback for current ideas and projects, and future products. The Stage-Gate reviews the ideas on an individual basis and the gatekeeper gets to decide whether the ideas are good or not at the end gate. The risk of this methodology is that innovation concepts can be stopped too early, a low level of knowledge held by the gatekeeper can lead to poor judgements being made on the project. Reviewing ideas individually also results in losing sight of the budget constraints.

Tidd & Aleman (2016) argue that the mobilization of the whole organisation to develop new ideas was is significantly associated with superior innovation performance. As was mentioned in Section 3.1.2, ideas build on ideas and external and internal stakeholders can improve and build ideas further. Therefore, the process of ideation and idea screening needs to become a separate process (from the Stage-Gate) in which the idea portfolio is managed as a whole and linked to external factors, such as budget constraints or the portfolio balance.

The spiral development methodology identified as the build-test-feedback-revise process (Appendix E: Stage-Gate development) offers agility and flexibility in the innovation management process (Cooper, 2014a). The reasoning behind the fast iterations and cycles is to fail fast and cheap. However, the process is still visualised as a sequential process, while the process happens cyclic. Therefore, the model needs to introduce feedback loops, scalability, and different entry points since not all activities are always needed.

3.3 INNOVATION PORTFOLIO MANAGEMENT

Innovation portfolio decision-making is a dynamic resource allocation process (Section 3.3.2) that takes into account; the strategic considerations across projects in the portfolio, and interdependencies between projects, while dealing with multiple decision makers who are often dispersed across locations (Chao & Kavadias, 2008; Cooper et al., 2001b). The process revolves around four main goals: **(1)** maximizing the value of the innovation portfolio, **(2)** balancing the diverse types of projects in the innovation portfolio, **(3)** Aligning the innovation portfolio with the firm's strategy, **(4)** carrying out the right number of projects in relation to the resources available.

3.3.1 FROM PROJECT TO PORTFOLIO

The concept of portfolio management for new product development is not new. Over the decades, the topic has surfaced in various forms. These include "R&D project selection", "R&D resource allocation", "project prioritization" and "portfolio management" (Cooper et al., 2001a). However, portfolio decision-making in the context of the development of new products, Innovation project portfolio management (IPM), has only recently started to receive attention in the literature. Traditional portfolio models focus on existing businesses and allocate resources across these businesses. While innovation portfolio models focus on products that do not even exist yet and allocate resources to these. Because IPM deals with future situations and opportunities, a lot of the information required to make project selections is at best uncertain and at worst very unreliable (Cooper et al., 2001a).

Firms tended to use the Stage-Gate process in its original form, which is well suited for developing individual projects that are incremental in nature (Cooper, 2008). The increasing popularity of the Stage-Gate process, however, did not produce a significant improvement in the new product performance. As a result of developing numbers of incremental projects to fulfil short-term goals, the portfolios tended to become overloaded with too many projects that no longer reflect the longer-term strategic direction of the firm (Cooper et al., 2001b). At the same time, firms started to experience difficulty in managing their NPD portfolios. "Firms had to move from implementing NPD processes to manage individual projects, towards implementing portfolio management to manage multiple projects simultaneously" (Barczak et al., 2009).

The exchange of ideas is the principal driver for innovation. External linkages that a company develops over time and the investment in his network of relationships form a distinctive competitive capability. They can be formed into a competitive advantage when they provide additional distinctive capabilities such as technological ability and marketing knowledge (Casper & Whitley, 2004). The stakeholder relationships must therefore also play a role in the management of innovation portfolios. This would allow the stakeholders, in an open innovation arena, to position themselves better in the innovation process and facilitate a better management of external knowledge sources.

Innovation portfolio management is involved with methods and tools that ensure effective resource allocation among a list of innovation projects. The essential characteristic of innovation portfolio management, is that projects must be viewed together instead of individually. This "portfolio view" brings along several new considerations, such as **(1)** the importance of strategic alignment, **(2)** the scarcity of resources, **(3)** the interactions and linkages between innovation projects that other innovation management practices neglect, and **(4)** the dynamic nature of the innovation programme for which the innovation management process needs to be able to adapt to.

3.3.2 ALLOCATION OF RESOURCES

It is important to diversify innovation projects (i.e. diversification in short/long term, industry, low/high value projects) and spread out resources and risks, however, the portfolio must be managed to make sure the risks don't outweigh the benefits. Firms that try to 'hedge their bets' on innovation projects, achieve higher performance only if they redirect the resources from failing efforts to succeeding ones. Otherwise escalating hampers the performance (Klingebiel & Adner, 2015). Therefore, the resources must be effectively allocated so that a healthy portfolio balance can be achieved.

Resource allocation is the process by which development resources (R&D, marketing, capital) are allocated to certain activities, projects or even businesses. On the micro level resource allocation amounts to an R&D head assigning people to work on certain projects or tasks within projects. On the meso level resource allocation involves creating a prioritized list of projects and raking them in order by using predefined and agreed-upon ranking criteria. At the macro level it is as broad as deciding on how many resources are spent on each business unit in the corporation (Cooper et al., 2001b).

An innovation initiative is defined by the value it could generate if it became successful and the probability that it becomes successful. The potential value it could generate is fixed and known to all stakeholders. The probability of success, however, is dependent on two key factors: The difficulty the initiative represents to the company, and the resources allocated to the initiative. A more difficult initiative requires more resources than a simple one to have the same probability of success.

The senior management employs to choose the level of resources they should allocate to certain strategic projects. This decision process falls within 2 categories: top-down or bottom-up. In the top-down process, senior management defines a fixed resource level to the middle management (e.g. project manager) to oversee. The bottom-up process grants the middle management the right to determine the level of resources that should be assigned (Hutchison-Krupat & Kavadias, 2014).

Project selection is the process of allocating resources to innovation ideas and an important aspect of innovation portfolio decision-making (Hauser, Tellis, & Griffin, 2006). The lack of information is a big problem in making innovation selection decisions, especially for new products (Chao & Kavadias, 2008). The newer the product, the higher the uncertainty and the more difficult it is to estimate up-front what its potential could be. While the initial decision to commit resources to an innovation project takes place at the screening phase, firms must decide at each phase in the innovation process whether to continue development or 'kill' the innovation project. Therefore, the process of resource allocation should not be associated or limited by the concept of phases and be done in a frequent continuous manner (Alemán, Bohlin, Francis, & Davies, 2015; Cooper et al., 2001b).

3.3.3 PORTFOLIO METHODS

Portfolio methods are the specific tools or methods to select innovation projects or review the portfolio of innovations. To develop an innovation portfolio management (IPM) model that can be used as a IPM tool (see SRO, Sections 1.3 & 1.5), it is important to review the different innovation portfolio methods and decide upon the main methods that could serve as a base for the innovation portfolio management model. A common theme in the IPM literature is the belief that establishing best practices or adopting certain methods will improve innovation outcomes (Cooper et al., 2001a; Hunt et al., 2008). Several authors have examined the best practices of IPM (Cooper et al., 2001b; Coulon et al., 2009; Phaal et al., 2006). However, there is no single IPM method appropriate for all situations. Organisations need to customize their IPM process to suit their context surrounding the innovation (Tidd & Thuriaux-Alemán, 2016). Portfolio methods are usually ranked by means of their link to the four major goals in innovation portfolio management (see Section 3.3).

Coulon et al. (2009) showed that among the portfolio methods they studied, the ones that address all four major goals (highlighted in the beginning of this Section) were: **bubble diagrams**, **roadmaps** and **scoring models**. A study performed by Cooper et al. (1999), among 205 businesses from a variety of industries, showed that no one portfolio method has a monopoly in the field of portfolio management. Best performing businesses rely on an average of 2,4 different portfolio management methods per firm (i.e. between 2 and 3 portfolio methods) to help align the project selection process with the corporate innovation strategy. All the methods are somewhat unreliable, but by combining multiple selection methods the process could be honed in on the correct decision regarding the selection of projects (Cooper, Edgett, & Kleinschmidt, 2000). Therefore, the IPM tool envisioned (Section 1.5) should possess several portfolio methods that can complement each other.

Managers typically use several methods to assist them in making innovation project selection decisions. These methods range from financial methods for calculating individual project estimations to more qualitative methods that deal with the allocation of resources across the entire portfolio per the strategic goals. Financial methods refer to a wide range of mathematical techniques that are used to calculate the estimated financial performance of an innovation project. These methods represent innovation selection decisions as rigorous comparison of numbers, making it attractive for managers to use. This is probably why financial methods are the most popular tool used by managers for making project selection decisions (Cooper et al., 2001a). Several studies, however, found that firms that rely heavily on financial methods for making innovation portfolio selection decisions performed the worst in terms of innovation performance and result in poorly balanced and strategically misaligned portfolios (Cooper et al., 2001b; Hunt et al., 2008).

Several methods exist to estimate the expected value of an innovation depending on the preferences of the firm. In its simplest form, the expected value is defined as 'reward' and relates to the estimated cumulative sales revenue of an innovation. More rigorous methods include discounted cash flow analysis for calculating the net present value (NPV) of a project and its internal rate of return (IRR). The NPV is the current value of all future cash flows, discounted by the firm's cost of capital including a discount factor in case of higher risk projects. The IRR is the discount rate at which the NPV of an innovation project is zero. Firms that rely on these traditional financial methods, tend to penalize higher risk projects with higher risk premiums because the larger pay-out is usually further in the future, which leads to a short-term focus and incrementally innovation portfolio. These methods have been criticized, since the calculations are speculative especially in the case of more innovative projects for which data are uncertain (Chao & Kavadias, 2008; Cooper et al., 2001b).

Some projects are great and have huge NPV, but consume a lot of resources, making it impossible to do other less attractive but far more efficient projects that have lower NPV but can be done by using relatively few resources. The goal then would be to maximize the bang for buck. By taking the ratio of the item, one is trying to maximize (in this case the NPV) and divide it by the constraining resource (R&D resources required) to determine the Bang for Buck. The Bang-for-Buck method shown in Equation 1, was favoured by several managers. The biggest drawback of this method is that the method relies fully on financial analysis, which is only good as the data input. Financial estimates for innovations, especially in the earlier stages, are very inaccurate. The method also doesn't take strategic fit or right balance of projects into account. The method, however, helps to maximize the value of the portfolio of projects by recognizing that some projects are more efficient than others instead of just ranking project based on their NPV.

$$Bang\ for\ Buck\ Index = \frac{NPV\ of\ the\ project}{Total\ resources\ remaining\ to\ be\ spent\ on\ the\ project}$$

Equation 1 Bang for Buck portfolio method (Cooper, 2001c)

The parameters to be maximized (i.e. the project's NPV) is divided by the constraining resource to maximize the "bang for buck". Large projects (NPV) tend to rise to the top of the list, however the investment required linked to those projects tend to be high as well. If projects are ranked based on "project score/R&D spend" instead of just project score (NPV), the smaller but efficient projects that require much less R&D resources would rise to the top as can be seen in Table 3 (project 6). The management must decide what innovation projects can be done in the next quarter with a budget of €10 M. The Bang-for-Buck Index shows the ranking of the projects and based on the resource requirements the top three projects can be (further) developed.

Portfolio Ranking (€10M)

Project	NPV	Resource Requirements Remaining	Bang-for-Index	Immediate Resource Requirements (Next Quarter)	Cumulative Immediate Resource Requirements
Project 3	55	5.0	11.0	5.0	5.0
Project 6	24	4	6	1.3	6.3
Project 1	52	9.5	5.5	3.2	9.5
Project 2	40	10	4	1.4	10.9
Project 4	9.5	2.5	3.8	0.5	11.4
Project 5	4.5	1.4	3.2	1.2	12.6

Table 3 Calculation of the Bang-for-Buck Index and budget constraints (Cooper, 2001c)

Bubble diagrams (Figure 19) typically show innovation projects on a two-dimensional X-Y plot. The axes can be any dimension of interest. A frequently used one is risk versus reward. The bubbles represent individual projects (or clusters of projects) and their size usually expresses an important third metric, such as the project's resource requirements. Other examples of metric expressions are: the shape, the colour and their shading. The 'reward' can be a qualitative or quantitative estimation. Some firms devote a lot of effort to develop customized graphical portfolio evaluation tools to increase the amount of information and level of detail represented. These tools are often highly sophisticated, especially when advanced software programs are used to build three-dimensional bubble diagrams. It is important to make sure that the users won't experience any difficulty in interpreting the information they obtain from the graphical representation. Otherwise the diagrams could do some serious damage to the innovation process (Cooper et al., 2001b).

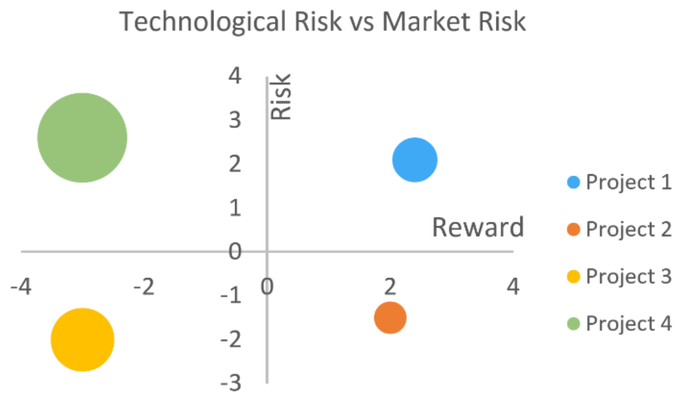


Figure 19 Innovation project risk vs. reward illustrated through Bubble diagram (Cooper, 2001c)

In scoring models, individual innovation projects are 'scored' (ranked) on a specified set of criteria, whereby preferably the criteria would have different weights. The scorings are then aggregated to yield a total score for every innovation project. The projects are then ranked by total scores to turn qualitative assessments into a quantitative evaluation that can support innovation project decision-making. Scoring models should be a rigorous set of qualitative criteria that can be used at decisive meetings, to help decision-makers select and prioritise the best development projects (Cooper, 2008). These models can also be used to help prioritize projects in innovation portfolio decisions by, for example, ranking the projects based on their attractiveness scores. Scoring models, however, only perform well if the criteria are well and explicitly defined (leaving no room for misinterpretation) (Barczak et al., 2009; Cooper et al., 2001b).

Roadmapping (Figure 20) is strategic in nature and gives the organisation some foresight into the future as to where the technology/product is going to go. The focus in roadmapping is the organisation, in the context of its environment. There are three primary processes that technology roadmapping needs to relate to; **(1)** Strategy formulation, i.e. identifying and defining future plans and directions for the organisation. **(2)** Innovation, roadmapping can show when new products are expected to reach the market. **(3)** Operations, i.e. the process of getting current products to the market.

The main features of roadmapping which require customization are (Phaal, Farrukh, & Probert, 2004): **(a)** Time. This dimension reflects the business purpose and industry conditions of the context. Usually there is more detailed information in the short- and medium- term areas of the map than in the long term. **(b**) Layers. This is the most critical aspect of customization. The top layer always relates to purpose and includes the drivers and requirements that must be met. The bottom layer relates to the resources. The central layer of the roadmap acts as the bridge between the capability and requirements and shows how the capability (or technology) should be delivered. **(c)** Supporting information. Additionally, to the information shown on the map, there is usually other data and supporting analysis required. The linkages between the layers are critical to identify the path the organisation should attempt to follow. The roadmaps communicate the plans and strategy. The method can combine product, project and resource information and act as an interactive dynamic dashboard driving the innovation process.

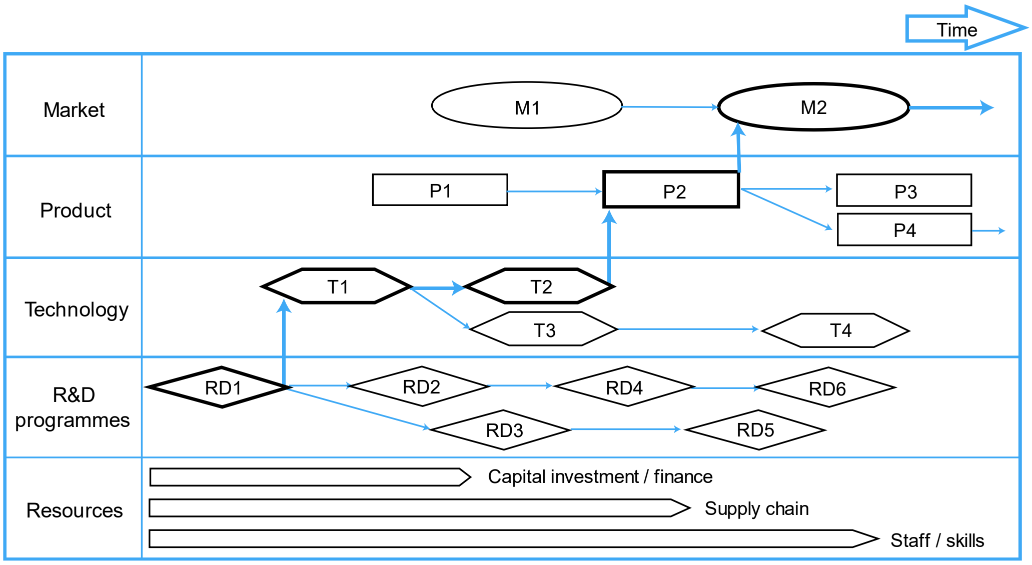


Figure 20 Technology Roadmap in innovation portfolio management (Probert, Farrukh, & Phaal, 2003)

Several studies also suggest using strategic buckets to facilitate portfolio selection decision-making (Chao & Kavadias, 2008; Cooper et al., 2001b; Coulon et al., 2009). This method (Figure 21) forces the resources to be split among various dimensions (e.g. by product line, by market, by product type). There are huge differences between incremental projects and genuine new projects. Many companies fail to recognize these differences and handle each project similarly. The solution is to translate the business strategy into clearly defined arenas (buckets) and to allocate resources to each. Firms that use the strategic bucket method may less easily discard radical innovation projects that are needed to grow the firm in the long term. This is probably why firms that use this method are more successful in terms of innovation performance (Barczak et al., 2009). However, the strategic bucket method does not provide a solution for companies where there is a high reluctance to kill projects. This is why it should always be used together with other portfolio methods (Coulon et al., 2009).

Figure 21 Split resources through Strategic Buckets (Chao & Kavadias, 2008)

Companies often struggle to achieve balanced portfolios that are aligned with the company's strategy. Bringing the portfolio methods to practice is often seen as a tough task. Portfolio management would take too much effort or the reporting too much time. To be effective, the IPM must also guide and take input from the ideation and ideation-management processes, as well as collude with both short-term resource allocation and long-term competence management. According to a study performed by Arthur D. Little on the trends and best practices in innovation management, best-practice companies would structure their IPM process in three steps (Alemán et al., 2015) (Figure 41):

1 Link to the strategy. Defining "what good looks like". A *target portfolio structure* provides a strong basis for decision-making and creates a common expectation and understanding about what should be achieved in the portfolio reviews. The expected portfolio structure should reflect; the organisation's strategy, technology and product roadmaps, market growth expectations, needed capabilities, available resources.

2. Optimize the existing portfolio. It is very important that the portfolio management and stage-gate review processes are closely aligned, as they depend on each other for success. The projects that are no longer aligned with the corporate strategy or that do not contribute to the desired portfolio balance should be stopped, even if they would meet gate-review criteria. Many organisations found that this process worked best when implemented on two levels. The first level is a high-level strategic review. This review would happen semi-annually and senior executives would review the balance and direction of the portfolio to ensure alignment. The second level would consist of a deep review with closer alignment to the stage-gate process. This review would happen monthly. The focus of this review would be to identify whether the current activities are in line with the strategy. Without the gate-review criteria, portfolio decisions might lead to bad projects (since the focus lies on strategy and not quality). On the other hand, without portfolio management, projects that are not strategically aligned would get selected and lead to bad portfolios (since the focus lies on quality and not strategy or portfolio balance). These two processes need each other to properly function.

3. Select new projects. Most organisations select their best ideas and push them into the stage-gate process, and by default into the R&D portfolio. Given a strong link to the strategy in the idea management process, this should result in a steady stream of ideas that are well aligned with the corporate goals. IPM can enhance this process by *pulling ideas* forward into the stage-gate process, rather than based on the idea management process. The risk in this process is that ideas get selected based on their explicit link to the strategic needs of the company instead of their quality.

Including the innovation portfolio management process in the idea generation and selection process (Section 3.2.2), therefore, helps to provide more direction and speed towards reaching a portfolio balance. Additionally, it also provides some strategic steering in the idea generation process, which would result in more ideas getting commercialized (Barczak et al., 2009).

3.4 STRATEGIC DECISION-MAKING

Innovation management transpires in an internal and external environment. The strategy of a company and the organisational structures are important aspects of the company's internal environment and effect the innovation management practices. The strategy illustrates the importance of innovation to the organisation, while the structure of the organisation, be it functional or divisional, determines the way innovation practices are organized. The innovation portfolio has become the representation of the company's strategy. It represents the direction towards which the organisation will move to in the near and far future. Therefore, innovation portfolio decision-making is often seen as a strategic decision-making process.

To develop an innovation portfolio tool that serves to support innovation portfolio decision-makers, it is important to gain a good understanding of the strategic decision-making process surrounding innovation, the risks it bears for the innovation process and what theory prescribes as possible solutions in avoiding these pitfalls. Innovation portfolio management decisions form an important part of the many decisions that are central to the innovation process (Krishnan & Ulrich, 2001). Strategic decisions, such as innovation portfolio decisions, are typically made under uncertainty, involve several decision makers, and do not have preprogramed solutions ready. They usually involve the identification and minimization of risks, and understanding, accepting and making of trade-offs. Strategic decision-making is a very complex problem that evaluates multiple conflicting criteria in decision making. It can also be classified as a Multiple-Criteria Decision Analysis (see Section 3.4.1).

This sub Chapter (3.4) starts by explaining what is understood of the concept of decision-making and its relationship with the innovation process (Section 3.4.1). The following Section elaborates on the risks uncertainty bring along in the innovation process and how the decision-making is effected by including external stakeholders (Sections 3.4.2 & 3.4.3). Lastly, Sections 3.4.4 and 3.4.5 will illustrate possible solutions proposed by the knowledge base for the many challenges that the innovation decision-making process bears.

3.4.1 DECISION MAKING

"Decision-making is a process of choosing among two or more alternative courses of action for the purpose of attaining a goal or goals" (Turban, Aronson, Liang, & Sharda, 2006 p.48). There may not always be a right decision among the available alternatives. Perhaps the right information was not available, or a better choice had not been considered. Multi-criteria decision making revolves around multiple-criteria evaluation problems, consisting of a finite number of alternatives and the alternatives are not explicitly known (Majumder, 2015). Decision-making and problem solving are interchangeable. A problem occurs when a process does not reach its defined goals, does not yield the predicted results, or does not perform as planned. Problem solving can also comprise with the process of identifying new opportunities or deciding which opportunity to exploit.

Decisions usually range from structured, semi-structured to unstructured ones. *Structured* problems are typically repetitive and routine problems for which the procedures for obtaining the best (or good enough) solution are known. Common goals are usually cost minimization and profit maximization. Examples are budget analysis, short-term forecasting, financial management. *Semi-structured* problems have some structured and some unstructured elements. Some examples are: production scheduling, credit evaluations, HR, new product planning. *Unstructured* problems are fuzzy, complex problems for which there are no standard solution methods. Examples are R&D planning, new technology development (Gorry & Scott-Morton, 1971).

The innovation decision-making process could differentiate a lot between firms. Innovation can be stimulated in two different ways (or a combination of both approaches). Firstly, in a top-down approach by developing from vision, mission and strategy goals. The senior management calls for ideas and explicitly states the area of high interest. By doing so they provide direction for both the technology- and market-domain and set the pace, targets and objectives and provide the funding. Secondly, in the bottom-up approach the innovation is originated from somewhere in the belly of the firm. Everyone can participate and come up with ideas and go through laborious process to first convince themselves and then convince several levels of management of the value of those ideas. This approach starts with those who are most affected by the problem and it can therefore be challenging to translate the ideas to the market needs (Cooper & Edgett, 2008).

3.4.2 UNCERTAINTY

Firms nowadays seem to take an overall market and customer orientation in selecting innovation projects for their portfolios. While innovation is, by definition, related to newness and change, it is also strongly related to concepts such as uncertainty. The use of intuition at the early selection stage further shows that managers acknowledge the uncertainties in innovation and try to cope with the lack of reliable information at this stage (Hart, Hultink, Tzokas, & Commandeur, 2003). Innovation management is an area in which the management of uncertainty is of prime importance. It comes with several occasions where decisions must be made regarding future funding. Decisions such as whether to cancel, continue or increase funding. The degree of uncertainty in these situations is high and therefore the senior managers, that are responsible for million-dollar budgets, have to carefully listen to the ones with the closest involvement and the most information and knowledge (Trott, 2012 p. 78). More information and knowledge becomes available with the passage of time; however, it is because time is limited that decisions are required. Therefore, many decisions are made with imperfect knowledge and so there is usually an element of judgement involved in most decisions.

To gain a better understand of this phenomena (uncertainty in product development) Pearson developed the “uncertainty map” (Pearson & Brockhoff, 1994). The map provides a framework for analysing and understanding uncertainty and the innovation process. Pearson’s framework, shown in Figure 22, divides uncertainty into two separate dimensions; uncertainty about ends (the eventual target of the project), and uncertainty about means (how to achieve this target). These dimensions are then divided into four Sections. Section 1 represents activities that involve a high degree of uncertainty in both dimensions. The target is not clearly defined and it is not clear how to achieve this target. This Section is also called 'exploratory research' and involves working with technology that is not fully understood and where potential markets have also not been identified. Section 2 is an area where the goal is clear, but there is high uncertainty on how precisely the company will achieve this target. This Section is called development engineering, because it is an activity that is ongoing in most manufacturing firms that are constantly looking for ways to reduce costs. In Section 3 the technology is clearly defined, but it is still unknown how the technology can be used in the most effective way. Section 4 is an area where there is most certainty. This area involves activities such as improving existing products or creating products by combining market opportunities with technological capabilities. Sometimes the target market and the product required is very clear. In other times, little is known about the technology and how it could possibly be used. Most companies have activities that lie between these two extremes, but such differing environments demand very different management skills and organisational environments. These will be determined by the extent of uncertainty involved and depend on the type of activity being undertaken. The map provides a way to identify the different management skills required for the innovation process.

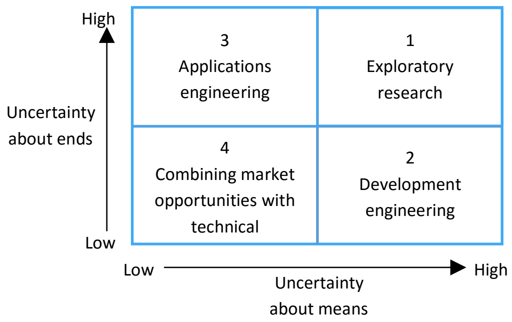


Figure 22 Uncertainty map (Pearson, 1994)

3.4.3 External stakeholders in innovation

So far, innovation has been an internal closed development process (see Section 3.1.2). However, the cost of building and sustaining the necessary technical expertise and special equipment is rising dramatically. Large and small high-technology firms acquire external technology/knowledge by means of strategic alliances with external parties and sharing their skills and resources. A strategic alliance is "an agreement between two or more partners to share knowledge or resources, which could be beneficial to all parties involved" (Trott, 2012 p. 234). Strategic alliances provide access to new technology and new markets and are the competitive weapon of the next century. Company's linkages with other organisations are key activities that are expected from the R&D departments. The ability to network in order to acquire and exploit knowledge enables the firm to enter new areas of technological development (Rothwell, 1992). Instead of researching and developing everything in-house, technology gets transferred to the acquiring firm. Technology transfer, as defined by Seaton and Cordey-Hayes (1993), "is the process of promoting technical innovation through the transfer of ideas, knowledge, devices and artefacts from leading edge companies, R&D organisations and academic research to more general and effective application in industry and commerce".

Nowadays, the practice is known and adopted by most organisations. Chesbrough and Brunswicker (2013) illustrated that among the 125 firms they studied in 2012, 78% were practicing open innovation. As such, the external environment must be made part of the innovation management process. Customers, universities and suppliers were the three leading open innovation partners in this study, in the form of customer co-development, informal networking, and university grants. The main strategic reasons they engage in open innovation is to establish new partnerships, explore new technological trends and identify new business opportunities.

However, sharing knowledge and technology through strategic alliances does not happen without any risks. Many firms have been avoiding the thought of sharing their ideas and technology with another company since their beginning. The total lack of trust lies at the heart of their unwillingness to cooperate. On the other hand, alliances have the tendency to cheat and use strategies to kill the competition (e.g. when organisations collaborate to introduce and enforce an industry standard). These alliances come with their risks, which is illustrated by the game theory "the prisoner's dilemma". In the prisoner's dilemma, the organisations in the alliances have the option to confess their mal practice or contradict it. If either confesses, the organisation that confesses will receive the minimal sentence (penalty) for becoming an informer while the other receives the highest punishment. If both don't confess they will both receive a sentence based upon some other lesser charge for which the police have evidence. If they both confess, the court will take this cooperation into account and pass a lighter sentence. Given this pay-off matrix both should confess.

All forms of collaboration (Table 4) involve an element of risk and control and require a huge amount of trust and control. It is the leakage of sensitive information to competitors that is of most concern to firms. It could lead to a competition rather than cooperation and a loss of competitive knowledge. However, there are several motives for establishing an alliance. This could be for sharing risk & liability, technology transfer benefits, better relationships with strategic partners, access to technology, standardisation, the use of distribution skills and to reduce R&D costs. These alliances can occur intra-industry, e.g. automobile manufacturers forming an alliance to develop technology, or inter-industry, e.g. the EU collaborating with several industries to reduce climate change.

Form of alliance	Benefits
Licensing	Licensing is a form of collaboration the licensor frequently performs the role of 'teacher' for the licensee. Licensing reduces the cost of technology development and provides a speedy entry to different technologies.
Supplier relations	These (usually informal) alliances are based on cost-benefits to a supplier. These could result in lower production costs if a supplier modifies a component to better 'fit' into the company's product, reduced R&D expenses based on customer's application information from the supplier, or reduced administration costs because of more integrated information systems.
Outsourcing	Often referred to as the delegation of non-core operations to an external entity specialised in that operation. The decision to outsource is often made to lower firm costs, conserve energy directed at firm's competencies, or to make more efficient use of worldwide labour, capital, technology and resources.
Joint venture	A joint venture is usually a separate entity with the partners to the alliance being equity shareholders. The costs and benefits from innovation projects are shared in a joint venture. These ventures are usually established for a specific project and cease to exist upon completion.
Collaboration (non-joint ventures)	The absence of a legal entity allows for more flexibility and provides the opportunity to extend the cooperation for many years. Examples of such collaborations are supplier relationships or university departments working closely with local firms on a wide variety of research projects with a common interest.

R&D consortia	A consortium is the situation where several firms come together to undertake a large-scale activity. This provides them with the opportunity to share the costs and risk of research, setting standards and sharing expertise and equipment.
Industry clusters	Clusters are geographical concentrated interconnected organisations, suppliers, service providers and institutions in a field. They increase the productivity of organisations based in the area, driving the direction and pace of innovation, stimulating the formation of new ventures within the cluster. Geographical, cultural and institutional proximity provide firms with special access, closer relationships, better information and other advantages that are difficult to tap from a distance (Porter, 1998).
Innovation networks	An innovation network is somewhat like a cluster, however not (per se) geographically close. A good example of this is Apple. Apple does not own most of the manufacturing plants for all the components of its products and relies on an established network of relationships to produce and distribute its products. Firms, universities, governmental agencies and competitors with an established track record within this network might get involved in additional activities such as concept testing and product development.

Table 4 Different forms of strategic alliance (Trott, 2012 p.239)

Inward technology transfer sometimes comes with its limitations and barriers. A good example is the Not-Invented-Here (NIH) syndrome, where new ideas and technologies from outsiders get rejected for its likelihood of being inferior because it was not invented in-house (Katz & Allen, 1982). But even if the employees would accept the external sources of knowledge and technology, without the absorptive capacity it would not be able to do so. “An organisation’s ability to evaluate and utilise external knowledge is related to its prior knowledge and expertise and this prior knowledge is, in turn, driven by prior R&D investment” (Cohen & Levinthal, 1990). Thus, R&D expenditure is an investment in an organisation’s absorptive capacity and therefore to obtain full value from external knowledge.

“For inward technology transfer to take place, members of the organisation must show an awareness of and a receptivity towards knowledge acquisition” (Trott, 2012 p.363). The internal and external environments must be continuously scanned for relevant information that can be utilised to develop associations with internal knowledge. These associations can lead to the creation of new business opportunities. For the organisation to learn, the knowledge must be embedded in skills and know-how for the organisation. It is when the knowledge is accepted and assimilated in the organisation widely that learning has truly taken place (Trott, 2012 p.363).

Providing that established and new alliances, relationships and other linkages of knowledge sources are seen to deliver a competitive advantage, they must be properly managed, controlled, maintained and strengthened. This could be done by managing the complex interactions that occur in the (open) innovation arena. The interactions between new technological capabilities and emerging societal needs are critical aspects of the innovation process, but have been underexposed in current models (Berkhout et al., 2010). The CIM framework (Figure 16, Section 3.1.2) attempts to capture the iterative nature of the network processes in innovation and illustrates this in the form of a continuous innovation circle with interconnected cycles. Innovation is the result of knowledge and information linkages, partnerships with those having the necessary capabilities (by means of open innovation), and the entrepreneur who is positioned as a ‘circle captain’ (e.g. Shell in the example in Section 3.1.2 as part of the Game Changer programme). The model helps to identify knowledge and technology flows between several stakeholders and positions them appropriately in the innovation arena. The model can be used to help identify and illustrate these flows and manage the strategic alliances throughout the innovation projects (more in Section 5.5).

The case of Shell

To illustrate the importance of networks for the innovation process, a look at Shell is taken. Shell is a large corporation and exists of several Innovation Support teams that are linked to external parties. Some examples of these teams are: Technology Ventures, where Shell ventures interesting external technology developments; Shell Tech Works, where references from other industries are used to implement them in Shell's own R&D; and Game changer, which is basically an incubator of Shell. These teams have a direct link to the technology officer (CTO). The CTO is the most important person in terms of innovation and R&D and manages the complete R&D portfolio.

The Innovation Research & Development Subsidy Desk department (IRD-SD) within Shell scans the resource landscape of Shell and filters the projects it comes across as 'interesting to work with external partners and/or other companies'. These projects are then matched with existing or upcoming subsidy programmes and the department advises the internal and external parties on how to get those projects going and running. They do this for the "whole" of Shell. They like to call themselves a one-stop shop. An example of this, is the collaboration of the IRD-SD with Game Changer. The IRD-SD department helps the Game Changer team, by scouting for new ideas internally and scouting the external landscape for promising ideas that can be nurtured by the Game Changer programme.

The corporation has a very long-term orientation (40 years). However, it would not solely focus on strategy or profit for its innovations (though all projects must relate to the strategy of Shell). The corporation would sometimes develop certain innovation projects for the creation of networks, because they want to be able work together with certain leading universities, research institutions or companies. In these cases, they would engage in programmes without wanting any money out of them. They would develop the projects just for the network or the know-how. In other cases, they would focus on pushing certain markets for solutions that Shell as end-users could use. An example is the field of robotics. Shell does not develop any robots, but they do use the latest generations of robots and sensors in e.g. their plants. When they have the feeling that the market is not developing as fast as they would like to, they would set up private funding or subsidy projects where they could support SME's in developing new generation robots. The IRD-SD department would then provide help together with a national or European subsidy programme and position themselves as co-subsidiary (and entrepreneurs / technology brokers).

The case highlights many activities performed to facilitate and manage innovation. The internal linkages between departments (e.g. IRD-SD with the other departments) and external linkages with other organisations or public entities to identify and link subsidy opportunities and make more innovations viable. Together with the need to invest in a strong network to accelerate technology research and 'pull' new functions (right side of Figure 14, Section 3.1.2).

3.4.4 Decision Support System and Knowledge Management

More and more companies are adapting their innovation management practices to their (business) context. Innovation is a complex problem and complex issues (e.g. involving information, communication , sustainability and growth) are often characterized by insufficient insight, insufficient solution tools and a great diversity of stakeholders (Berkhout, 2000). "An integrated tool is needed to support the intuitive decisions managers to tailor their innovation approach to the type of innovation, organisation(s), industry and country/culture" (Ortt & Van Der Duin, 2008).

Cooper (Cooper et al., 2001b p.18) highlighted the role as facilitator of decision support systems in the innovation portfolio management process. He refers to decision support systems as mathematical models that include the decision maker as part of the system. These systems would provide information, models, and tools to display and analyse data and allow the user to control the methods to formulate and evaluate alternative decisions. This research project will use a slightly adjusted definition of Decision support systems that was provided by Keen and Scott (1978): *"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision maker".* The original definition was focussed on semi-structured problems; however, technology has improved a lot since then and has become more capable of supporting decision makers with unstructured decisions (such as product development).

Decision Support Systems (DSS) and knowledge management are interrelated to each other. For example, decision makers may use stored knowledge for making decisions. All phases of the decision-making process can be supported by improved communication through collaborative computing via group decision support systems (GDSS) and Knowledge Management Systems (KMS).

Since innovation revolves around multi-criteria decision-making (Section 3.4.1), it requires multi-criteria decision analysis (MCDA) to evaluate the process (Wang, Jing, Zhang, & Zhao, 2009) in practice. This decision support approach helps to address a complex problem, such as innovation, featuring uncertainty, conflicting objectives, different forms of data and information, and diverse set of stakeholders with different interests. Wang et al. (2009) proposes a four phase method to help illustrate the process of building an MCDA. The process revolves around the definition of goals and alternatives, selection of criteria, and assigning normalized scores to the selected criteria. Followed by determining the weights of the selected criteria and the preference orders of alternatives (ranking). Finally, selecting the "best" alternatives.

There are two methods usually to determine the weights: the equal weights and the rank-order weights. The equal weights method requires minimal input and knowledge of the priorities from the decision maker. The method, however, ignores the relative importance among criteria. Therefore, the rank-order weighting method seems a better candidate for the evaluation of innovation projects.

The rank-order weighting methods exists of three categories: subjective weighting method, objective weighting method and combination weighting method. The subjective weighting methods depend on the preference of decision-makers, not on the quantitative measured data. In contrary to this method, the objective is obtained by mathematical methods based on the analysis of the initial data. None of the two methods is perfect. A combined weighing method might be most appropriate in determining the criteria weights (Wang et al., 2009).

Understanding how resource allocation decisions are made within organisations has been an important topic in economics (Penrose, 1995). Even though knowledge is a resource, effectively managing it allows organisations to get more value out of all the resources. Current innovation models build upon the idea that we live in a knowledge economy, and knowledge is a competitive weapon for innovation success (see Section 3.1.2). Therefore, the sources of knowledge must be effective managed to reach their full value and be able to gain a competitive advantage in innovation.

A slightly adapted version of the definition of Knowledge management (KM) proposed by Turban et al. (2006 p.481) will be used: "Knowledge management is the systematic and active management of ideas, information, and knowledge residing in an organisation, coming from external and internal sources”. KM allows for effective and efficient problem solving, dynamic learning, strategic planning, and decision-making. The process helps to identify, codify and structure knowledge so that it can be re-used and shared in a formal manner to reach its full value. Knowledge management systems (KMS) are IT solutions that make KM available throughout the organisation and help to share and disperse knowledge appropriately for maximum organisational benefit.

It is important to note that knowledge differs itself from data and information in the IT context (in KMS). Whereas data are facts, measurements, and statistics, information is organized or processed data that is appropriate within the time frame of applicability. Knowledge is information that is contextual, actionable, and relevant (Turban et al., 2006 p.482). In other words, obtaining appropriate (e.g. current information) information is only useful if the user has the knowledge to use the information and action from it (absorptive capacity). Thus, having information does not allow for problem solving, but possessing the knowledge does (assuming the right information is available).

GDSS is a computerized system that can facilitate the solution to semi- and unstructured problems involving groups of decision makers. The system facilitates the communication by helping people explain and justify their suggestions and opinions and provide support for the knowledge acquisition process. The system also provides support for meeting participants in the decision-making process, helping to improve the productivity and effectiveness of meetings. Overall, GDSS help to speed up the decision-making process and improve the quality of the resulting decisions (Turban et al., 2006 p.452).

Turban and his colleague propose several reasons for decision-makers to utilise computerized decision support systems (2006). Their reasoning’s are translated towards supporting the innovation decision-making process, as illustrated in Table 5.

Capabilities	Decision support	Innovation decision support
Speedy computations	Enabling the decision maker to perform many computations quickly and at a low cost.	The system can evaluate many alternatives in seconds, this can be critical when the innovation portfolio (all the current innovation projects and previous innovation projects) must be analysed and processed during gatherings of executives, where time is of relatively high importance.
Improved communication & collaboration	Enable group decisions, where the members are geographically dispersed.	This allows for collaboration among innovation stakeholders. Internally within the organisation, but externally e.g. along the supply chain where information must be shared with customers and suppliers.
Increased productivity of group members	To bring group decision makers together, especially experts, can be costly. Computerized support allows for distant collaboration and increases productivity.	Computerized support may allow for fast collaboration, where innovation concepts and prototypes can be shared, evaluated and improved at different locations (through the exchange of information & simulation).
Improved data management	Many decisions involve relevant information and knowledge, which can be stored in the organisation. Computers can search, store and transmit the needed data quickly, economically, securely and transparently.	As technology builds on technology, relationships are important to be maintained and used over and over, and open innovation arenas can include a vast amount of information and knowledge exchange (Section 3.1.2), it is important to be able to codify, store, recall and re-use this information and knowledge.

Quality support	Computers can improve the quality of decisions by analysing more data, evaluating more alternatives, improve forecast, and collecting the insights of experts (some of whom are remotely located) quickly.	Innovation is risky due to its uncertainty, which is due to a lack of information. The system would allow for fast information gathering to assist the innovation decision-makers in comparing many possible scenarios, and assess the different levels of impacts quickly, and collect information and knowledge from internal and external experts remotely.
Agility support	Competition is not only dependent on quality, but also on timeliness, customization of products and customer support. Also, organisations must be able to frequently and rapidly change their innovation processes and structures to adapt to the changing environments.	The system allows for iterative product customization throughout the development phase. Additionally, the system allows for the quick customization of innovation management methods and processes. And scans the organisation's environment to quickly adapt the system to the changing environment.
Overcoming cognitive limits	The human mind has only a limited ability to process and store information. People sometimes have difficulty recalling and using information due to their cognitive limits. The problem-solving capability of an individual is limited when a wide range of knowledge and information is required. Computer systems allow decision makers to overcome this limit by quickly accessing and processing big amount of store information.	Since innovation is linked with a lack of information, the innovation decision-maker often make decisions based on intuition (Section 3.4.2). There is a limit in the amount of information and knowledge the decision-maker can process. The system can quickly gather, analyse internal and - external knowledge and information, and present the information to the decision-maker to make more informed decisions.

Table 5 Why we should use computerized decision support systems for innovation (adapted from Turban et al., 2006)

3.4.5 DECISION SUPPORT INTELLIGENCE

The main benefit of intelligence in decision support systems, also referred to as 'business Intelligence', is the ability to scan internal and external information sources for problems and opportunities. "Business Intelligence (BI) is an umbrella term that combines architectures, tools, databases, analytical tools, applications and methodologies" (Raisinghani, 2003). It means different things to different people. The major objective of BI is to enable interactive access (sometimes in real-time) to data, to give managers the ability to conduct appropriate analysis. By analysing past and current data, situations, successes and failures, decision-makers obtain valuable insights that enable them to make more informed and better decisions (Zaman, 2005).

Tidd & Alemán (2016) argue that external sources of business intelligence (i.e. lead-users, suppliers, and external experts) are often more reliable for capturing valuable data. The data, however, needs to be structured and tested against internal know-how before it can be used. The use of external sources of business intelligence provides early signals to product and technology managers that seek to improve their portfolios over time, and thus helps to balance incremental and radical innovations (Tidd & Thuriaux-Alemán, 2016). Other examples include the identification of relationships among projects, technologies and stakeholders; identifying similarities through KMS's between past situations and how to handle re-occurring problems; generating alternative courses of actions and forecasting future consequences of these various alternatives; and rapidly identifying a best or good-enough alternative.

Business Intelligence helps to achieve something critical in the innovation portfolio management process: actual data and numbers. As was illustrated in Section 3.1.2, innovation revolves around many stakeholders and lots of knowledge and information flows. Therefore, it is critical that the right tools exist that can share and present these data flows as fast as possible. The early achievement of knowledge of trends, competitive activity, opportunities for collaboration, external knowledge sources, and customer feedback, provide the decision-maker with valuable resources that allow for better decisions to properly allocate the resources and kill projects in time.

Business performance management can provide the right tools to succeed in managing innovation processes and portfolios. Business performance management (BPM) is a portfolio of applications and methodologies that contains BI architecture and tools in its core (Turban, Aronson, Liang, & Sharda, 2006 p.27). The process resembles the innovation portfolio management process and includes the monitoring, measuring, and comparing of performance indicators by introducing the concept of management and feedback. BPM helps to enforce the corporate strategy and is usually combined with the balanced scorecard methodology (Section 3.3.3).

Another example of where Intelligence can be of support is the idea generation process. An electronic brainstorming tool could help to stimulate the free flow of creative thinking: ideas, words, pictures and concepts. The tool would bombard the user with many ideas to help the user move from an analytic mode into a creative mode. This is because people tend to anchor their thoughts early on, using their first ideas as springboards for other ideas. This would result in minor variations of the original ideas and no significantly new ones (Turban et al., 2006 p.469). The idea generation tool is a Group Decision Support System (GDSS) and promotes participation in the creativity process and supports project collaboration through the enhancement of digital communication with various tools and resources. The GDSS sees the ideation process as a collaborative effort. One person's idea triggers another's ideas, which triggers even more ideas. The results of the idea-generation sessions can be stored so that results can be carried over from one meeting to another to enhance the creativity of more people.

3.5 CONCLUSION

> *SRQ1: Which theories are linked to an Innovation Portfolio Management multi-criteria decision-aiding model, that can integrate with the user's current innovation practices, adapt to the user's context, and cope with the criteria of the users regarding the model's complexity and resource intensity?*

Literature research identified several insights, methods and models that can contribute to reach the research objectives (Section 1.3). Section 3.1.2, showed that innovation is the continuous accumulation of knowledge and builds on knowledge from prior innovations. Innovation success is dependent on the management of internal and external information and knowledge sources. The CIM model (Berkhout et al., 2006) illustrates these communication and knowledge linkages and helps innovation stakeholders to identify their position and role in the innovation arena and their relationship towards other stakeholders. However, the way the CIM model portrays the innovation process would provide difficulty for innovation managers to perform the innovation process in a timely manner, as it doesn't illustrate any phases or steps to guide the managers. Nonetheless, it illustrates the many relevant knowledge exchanges, and could act as an effective communication instrument by connecting experts from different organisations and different disciplines to help accelerate and improve the innovation process.

Section 3.2.2 showed that the innovation gating-approach (Stage-Gate process) is the most popular methodology among the innovation management models. This is because of its project management benefits. This method has evolved over the last decades. The model was made more agile, flexible, and allows for stages to overlap one-another. The new model (Section 3.2.2) also introduces an iterative development process that incorporates feedback loops from users. These improvements, however, still fail to highlight the importance of external information and knowledge linkages throughout the innovation process, the strategic alignment, innovation portfolio balance, budget restrictions, internal linkages to prior knowledge, and remains static in the sense that its stages are linear and do not allow for stages to be skipped or previous stages returned to.

The Section (3.2.2) continues to define the process of idea management and argues that the process needs to be performed in a more holistic manner, i.e. by incorporating the whole organisation in the idea generation and idea screening process. This change would allow for the creation of more novel and creative solutions, and reduce the risk of terminating potential initiatives.

Section 3.3 illustrates that innovation portfolio management revolves around four main goals: **(1)** maximizing the value of the innovation portfolio, **(2)** balancing the diverse types of projects in the innovation portfolio, **(3)** Aligning the innovation portfolio with the firm's strategy, **(4)** carrying out the right number of projects in relation to the resources available. The Innovation portfolio management process involves several methods and tools to ensure effective resource allocation among a list of innovation projects. Section (3.3.1) argues that **(a)** the technology linkages between multiple development projects need to be identified to help recognize their synergy or incompatibilities, and **(b)** the alliances and partnerships of an organisation should be managed and part of the innovation management process, because the relationships possess a distinctive competitive capacity.

Section 3.3.2 illustrates that organisations must decide at any point in the innovation process, whether to continue, kill or change the resource allocation of an innovation project. Therefore, the process of innovation portfolio management is present parallel to the innovation process. Section 3.3.3 followed by illustrating several tools or methods to select innovation projects and review the innovation portfolio (portfolio methods). Best practice organisations usually introduce two or three portfolio methods in their innovation portfolio management process. Financial portfolio methods perform the worst among the innovation portfolio methods, and result in poorly balanced portfolios. On the other hand, strategic portfolio methods perform the best, especially bubble diagrams, roadmaps, and scoring models. These three methods address all the four major portfolio goals and would serve as a good basis for innovation portfolio management model. The Section also highlights that these methods require the ability of customization to suit the organisation's context.

The Section ends by proposing three critical activities for the portfolio management process, existing of **(1)** the definition of the strategy and linking the innovation portfolio to it, **(2)** optimising the existing portfolio, by deciding whether to kill, continue, or change the resource allocation of projects in the current innovation portfolio, **(3)** pulling new ideas straight into the development cycle (more in Section 5.3) to help accelerate the process of reaching a portfolio balance. These activities help to illustrate the linkages of the innovation portfolio management process with the other innovation management practices for the innovation support framework (Section 1.5).

The Chapter continues to highlight the importance of fast communication and information gathering and sharing through IT solutions, to support the information and knowledge exchanges throughout the innovation process. The IT solutions would come in the form of intelligent Decision support systems that possess knowledge management capabilities (Section 3.4.4). This allows innovation decision-makers to utilise the knowledge available throughout the organisation and external to the organisation, and provide the ability to participate in remote real-time collaboration. Business intelligence complements the decision support systems, by integrating external sources of information, knowledge, skills, and performing automated actions to help reduce the resource intensity of the IPM tool (Section 3.4.5).

This research attempts to bring elements from both the Stage-Gate models and CIM model, by incorporating the project management benefits of the gating approach (Section 3.2.2), and the continuous view of the CIM model with its many information and knowledge linkages throughout the innovation process. The portfolio management process is perceived as present throughout the innovation process and is associated with the organisation's strategy. The models, activities, and many information and knowledge exchanges are supported with Decision support systems that incorporate a level of Business intelligence and Knowledge management. The systems gather and store knowledge, and make it accessible throughout the organisation for current and future development projects.

> *SRQ2: What are the relevant requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?*

The relevant requirements, illustrated in Table 6, were derived from the theoretical domain. They help to define the innovation portfolio management process and how it can present itself parallel to the innovation process, while influencing and getting influences by the external environment. Design requirements T13, T14, T15, and T16 are aimed for the first concept design of the IPM tool and illustrate a basis set of methods. Due to budget restrictions only these concepts could be chosen and implemented. While T2, T5, T8, T9, T20, T21, T22, T23, and T24 serve as design requirements for an innovation decision support system that serves to complement the IPM process in practice and presents itself as possible improvements to the first concept of the IPM tool. The rest of the design requirements were derived for the innovation support framework and illustrate what kind of innovation practices are present parallel to the innovation process and what their relationship with the innovation portfolio management process is.

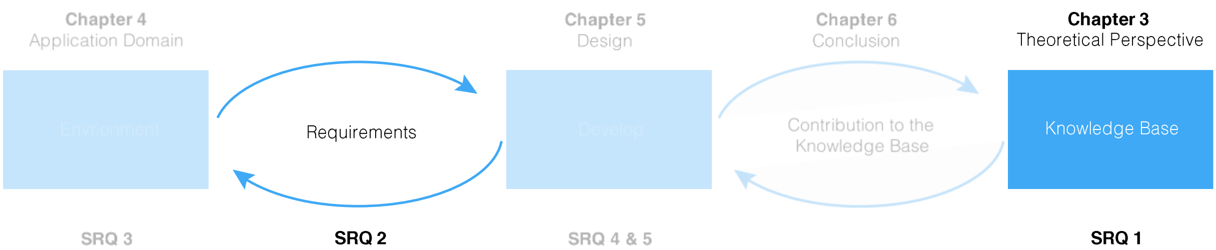
No	Requirement	Design requirement for artifact	Source
T1	To succeed in innovation, an organisation must possess the ability to acquire and utilize knowledge. Innovation is the continuous accumulation of knowledge and can be accelerated and improved through the incorporation of external stakeholders, by means of iterative feedback loops to better understand society's needs and concerns.	Facilitate linkages to external information and knowledge sources throughout the innovation process and allow for iterative prototyping, feedback, and testing with external parties during the innovation process.	(Barczak et al., 2009; Berkhout et al., 2006; Chesbrough et al., 2014; Von Hippel, 1976, 1986, 2001) **Section 3.1.2**
T2	For the creation of novel and more radical innovations, all four of the CIM knowledge and information cycles must be present. Current innovation models often only highlight the linkages to the user, customer and supplier.	Incorporate the CIM model to help identify and address all the relevant information streams, cycles and stakeholders throughout the innovation process.	(Berkhout et al., 2010) **Section 3.1.2**
T3	Innovation is a continuous process rather than a linear one, whereas learning and improvements occur in all stages. Phases can happen parallel to each other rather than being separated by management decision gates.	Highlight the permeable gates, many feedback loops, and linkages between the phases in the innovation management process.	(Berkhout et al., 2006, 2010) **Section 3.1.2**
T4	Innovations are linked to previous similar products and are not a product of their own.	Address the linkages between current and previous innovations (i.e. technology, information, stakeholders).	(Berkhout et al., 2006; Christensen, 2013; Schumpeter, 2013) **Section 3.1.2**

T5	Innovative ideas with potential value, should not be killed when the timing is wrong (i.e. not enough budget, knowhow, wrong innovation portfolio balance, customer cannot absorb the new technology now), but be stored to and revisited when its potential value can be obtained (e.g. through licensing, when the market is ready, when the complementary technologies are ready).	Address the storage of ideas and innovation projects and link the process to the innovation portfolio management and innovation management processes.	(Christensen, 2013) **Section 3.1.2**
T6	Idea generation and idea screening must not be limited to individual participation but also capable of being performed together with the 'whole' organisation and/or external stakeholders.	Separate idea generation and idea screening from the innovation (project) management process.	(Tidd & Thuriaux-Alemán, 2016) **Section 3.2.2**
T7	Iterative and spiral developments, such as the build-test-feedback-revise model (0Appendix E: Stage-Gate development), are often not linear in real-life and return to previous stages. In some cases (e.g. in IT) the process skips testing and puts the product on the market first (e.g. beta products).	Illustrate the build-test-feedback-revise as a development cycle and Introduce feedback loops in the cycle.	(Berkhout et al., 2010) **Section 3.2.2**
T8	Stakeholder relationships are seen to hold a distinctive competitive capability and therefore must be effectively managed (i.e. the recognition of stakeholders, positioning of stakeholder within the innovation project, storing and accessing previous collaborations, improving current relationships).	Address the integration of relationship management within the portfolio management process and innovation project management process to help manage and utilize the portfolio of relationships.	(Casper & Whitley, 2004) **Section 3.3.1**
T9	Organisations often develop multiple products in closely related markets, resulting in their innovations being developed showing synergy or incompatibilities and may complement or substitute one another.	Make interactions/linkages between technologies visual through KM and portfolio methods (e.g. technology roadmaps).	(Cooper et al., 2001b) **Section 3.3.1**
T10	Firms must decide at each phase of the innovation process, whether to continue, kill or change the resource allocation of an innovation project. The process of resource allocation, therefore, must be done frequently in a continuous manner and not be limited by the concept of phases.	Incorporate Innovation portfolio management and frequent portfolio reviews throughout the innovation process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.2**
T11	Innovation ideas and projects need to be evaluated individually and holistically (portfolio of innovations). And these two processes need to be closely aligned and need each other to properly function. Innovation portfolio (holistic) decisions must overweigh the other innovation management (individual) decisions.	Define and illustrate the relationship between Innovation project management and innovation portfolio management. And present Innovation portfolio management parallel to other innovation management processes.	(Alemán et al., 2015) **Section 3.3.3**
T12	External dynamics and changes (e.g. market transitions and trends) must be monitored and analysed throughout the innovation management process, to stop, kill or change resource allocation of innovation projects. In current gating models (e.g. Stage-Gate) this information is only reviewed at the decision 'gates'.	Address the linkages between the innovation process and relevant information sources external to the process. And present the external dependencies continuously throughout the innovation process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.1 & 3.3.3**
T13	Innovation portfolio management must include more than one innovation portfolio method with an average between two and three methods. These methods should complement each other.	Include two to- four complementing innovation portfolio methods in the IPM tool (see SRO, Sections 1.3 & 1.5).	(Cooper et al., 2000) **Section 3.3.3**
T14	The combination of innovation portfolio methods jointly must address all four major innovation portfolio goals.	Incorporate at least two out of the three innovation portfolio methods recognized by Coulon to do so (bubble diagrams, roadmaps, scoring models).	(Coulon et al., 2009) **Section 3.3.3**
T15	Financial portfolio methods perform the worst in terms of innovation performance, the focus should lie more on strategic portfolio methods.	Focus on strategic portfolio methods, rather than on financial portfolio methods.	(Cooper et al., 1999) **Section 3.3.3**
T16	The combination of innovation portfolio methods must be customizable (i.e. choosing methods, parameters, criteria, weights, labels) to better suit the context surrounding the innovation.	Address the ability of customization, by the user, within the innovation portfolio methods.	(Cooper et al., 2001b; Coulon et al., 2009; Phaal et al., 2006, 2004)

		Section 3.3.3
T17 Innovation portfolio management must be present in the process of idea generation or idea screening to select project developments and accelerate the process of reaching a portfolio balance.	Address the linkages of idea generation, idea screening and innovation portfolio management.	(Alemán et al., 2015) **Section 3.3.3**
T18 To perform innovation portfolio management and help align innovation projects with organisation's strategy, the strategy needs to be defined prior to the process and revised when needed. It is important to create a common expectation and understanding about what should be achieved through the process.	Incorporate the innovation strategy and link it to the innovation portfolio management process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.3**
T19 Innovation portfolio management reviews should include the following three practices: definition and revision of the strategy, optimisation of the existing portfolio, and selection of new projects.	Address the three best-practices performed in innovation portfolio reviews.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.3**
T20 Innovation decision-making differs per organisation and even per innovation project, therefore the innovation management model must include flexibility in the roles and decision structure within the organisation to better suit the innovation environment.	Address the customizability and adaptability of Innovation management models to the innovation environment (organisation, innovation project, external context).	(Cooper & Edgett, 2008) **Section 3.4.1**
T21 Linkages to external data and knowledge platforms (such as subsidy opportunities, knowledge and skills services) must be incorporated into the innovation management decision support system to help reduce and share the risks of innovation.	Integrate data and information gathering linkages throughout the innovation process.	(Turban et al., 2006) **Section 3.4.4**
T22 Utilise computerized (group) decision support systems to allow for remote group decision-making, by facilitating information and helping decision-makers elaborate and justify their suggestions and opinions.	Incorporate computerized (group) decision support systems to facilitate the many linkages and iterative feedback loops through which knowledge and information is exchanged throughout the innovation management models.	(Cooper et al., 2001b; Turban et al., 2006) **Section 3.4.5**
T23 Knowledge management systems are needed to store, access and utilise knowledge throughout the organisation and help share and disperse this knowledge for maximum organisational benefit (see Design requirement 1).	Address knowledge management systems as a complement to decision support systems.	(Turban et al., 2006) **Section 3.4.4**
T24 To reduce the resource intensity, decision support systems should include a level of intelligence to help (1) scan the internal and external information sources for problems and opportunities, (2) identify relevant stakeholders, (3) identify relationships among projects, technologies and stakeholders, (4) identify similarities with past situations through knowledge management systems and how to handle these.	Address the benefits and importance of business intelligence within decision support systems.	(Turban et al., 2006) **Section 3.4.5**

Table 6 Design requirements derived from the theoretical domain

Sub-research questions 1 and 2 have been answered (SRQ2 partly). The knowledge they bring is utilised in the next Chapter to better understand the current solutions deployed in the application domain, and analyse the needs of the application environment.



4 APPLICATION DOMAIN

This Chapter explains the practical environment in which IPM is performed and helps to better understand the application domain of the research. The Chapter helps to answer the following research questions:

> *SRQ2: What are the requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?*

> *SRQ3: To what extent do the currently employed solutions at the commissioning organisations, meet the identified requirements?*

The Chapter aims to provide the practice background on which the research is based and is exploratory in nature. Section 2.3 illustrated that to define the objectives for a solution in Design science research, it is important to possess knowledge of the state of the current solutions. The Chapter starts by discussing the current solutions deployed at the commissioning firms. Section 4.1 starts with the Provatool developed by Bax&Company. Followed by Section 4.2, which illustrates the EasyCrit tool developed by Critflow. These solutions are related to the requirements obtained from the knowledge base and help to provide design requirements for the IPM tool (Section 1.5). The Chapter ends with a few case studies in Section 4.3.1 to help illustrate the current innovation management practices and the relevant insights gained from lead-users. The Sections end with the practical requirements obtained that help to design the artifacts and support the application of the artifacts.

4.1 PROVATOOL

Twelve years ago, the commissioning firm of this research project developed and implemented an Innovation Portfolio Management (IPM) tool called "Provatool". The tool expanded their portfolio of consultancy solutions and supported their consultancy services by making their advice more tangible and visual for the clients to understand. In the last decade, the company stopped its services surrounding the tool, but recently noticed a need from their clients for an IPM tool.

The Provatool was developed in excel (Appendix , Appendix C, Appendix), in its time, not a very new and unique solution. The developer argued that firms bought the concept and not the underlying IT solution and thus the tool was positively received. The concept intrigued their interest and it was exactly what they were lacking in their innovation management. One the buyers was well-known for its innovations, and was awarded 'the most innovative company of Catalunya'. The CEO of this firm was in search for an innovation portfolio management tool for some time, however all the tools he found and tried were complex, costly and time consuming. The Provatool came during a window of opportunity; the CEO had a problem and the consultancy had a solution ready. The strengths of the tool perceived by its users were its *simplicity* (i.e. involving a handful set of portfolio methods), *price* and *effort intensity* (i.e. amount of time and effort needed to perform the process) compared to other solutions. These success criteria were also emphasised by Phaal et al. (2006). The tool was robust and developed on theoretical basis. It's simplicity, price and effort intensity made it economic and practical to implement. The tool was tailor made so that it integrates well with the organisations' other processes and tools. However, it did not meet an important criterion: it lacked in its flexibility to adapt to changes in the innovation structure, processes, environment, and strategy.

The Provatool existed of several portfolio methods (Sections 3.3.3). The main tools or methods to select projects or review the portfolio of innovations, are illustrated in Table 7. The developer of the Provatool (External expert 1; Appendix D: Interview list) highlighted that not all portfolio methods (Table 7) were received in the same positive manner. The combination of methods and the utilised software environment (MS Excel) resulted in several pitfalls and barriers for both developer and user. To name a few:

The *high risk of imitation* and *lack of user involvement*. The customer desired the ability to test the tool remotely in their company environment or up-front before purchase. This was not possible. The tool could easily be copied and therefore had to operate locally. Since it had to run locally, external parties could not participate in innovation portfolio management process. The tool could *not be customized* further without the support of the developer. "Providing a prototype that the client can play with and further customize would get the client more involved and help the user get a better understanding of the type of graphs he would like to possess in an early stage, to show his colleagues or top management" (External expert 1). This would result in a better co-development process of the tool. The importance of including users in the development was highlighted in Chapter 3 (Section 3.1.2). Customers can be incorporated as lead-users to better understand the user needs and improve the product design, by providing the prototype as a toolkit and allow the users to further customize it to suit their needs (Von Hippel, 1986, 2001).

The tool seemed to be less effort intensive than its competitors on release according to its previous developer (External expert 1). However, the tool, even though simple, is *time consuming and effort demanding* when related to current customer needs (regarding the input and visualisation of big amounts of information and data). The reasons for this are the inefficiencies and limitations of MS Excel. Clients had to go through several functions and tabs, just to change a value and see what kind of effect it would produce. The visuals were too static and resulted in unclear portfolio graphs where projects would overlap on another (e.g. Appendix). The use of MS Excel also created *no coherence* in the data that was being entered. Information could be adjusted by anyone without any restrictions or traces (there should be a process of learning, and building upon each other's insights).

The tool also provided potential future financial statements (services 3 & 6 in Table 7) (Appendix A: Future cash flow estimation), which in practice was rarely used. The reason for this, was that these methods tend to be very inaccurate compared to the situation in practice. Innovation decisions happen with a lack of information, methods for calculating future financial statements therefore tend to be highly inaccurate (Cooper et al., 2001b). Even though financial approaches are the most popular innovation portfolio methods and they dominate the portfolio decision-making in many organisations the methods generate poor results and poor portfolios when compared to strategic methods, such as scoring approaches (Cooper et al., 2001b; Coulon et al., 2009).These methods, therefore, should be avoided if possible (Section 3.3.3).

	Provatool services
1.	Scorecard evaluation
2.	Expected investments for the year
3.	Future cash flow estimation

4.	Bubble diagrams with several parameters
5.	Bar charts with the project investments per phase
6.	Future sales forecast
7.	Pie and bar charts with the resource allocation

Table 7 Provatool portfolio methods

The use of tailored strategic portfolio methods, such as scoring methods, strategic buckets, bubble diagrams, and ranking methods, was positively received by firms in general. The tool presented key information, which provided the clients with the right instruments to: **(1)** convince senior management to invest in more innovation projects, **(2)** base their portfolio decisions more on objectified data than solely on intuition (and reduce the tendency for projects that cannot really be justified to get selected (Cooper et al., 2001a)), **(3)** give more direction in the projects they choose to develop, **(4)** consider their portfolio balance and strategic alignment. The tool included the consultancy's service of revising and defining the strategy. After which the tool was tailored to the client, resulting in an easy integration of the solution within the currently deployed innovation management practices.

4.2 CRITFLOW - EASYCRIT

Critflow is an IT company and innovation consultancy (and one of the commissioning firms), that develops software tools for the facilitation of creativity and innovation. The company possesses an Innovation Management tool, called EasyCrit, and a client base using the product. The firm recognized the need for improved evaluation criteria to help manage the portfolio of innovation projects. To validate this need and obtain the criteria, several clients were asked to co-develop the improvements through the demonstration, feedback iteration, and share of insights as lead-users for the design requirements of the IPM tool (Sections 1.3).

EasyCrit follows a six stages innovation structure (Appendix I: EasyCrit innovation process). The linear and sequential process involves the following six steps. **(1)** First the organisation's strategy is defined and challenges are created to address them. These challenges are published within EasyCrit so that **(2)** users can create new ideas to tackle these challenges. The organisation defines three criteria (Figure 23), based on which **(3)** the innovation council can select the best ideas from. This number differentiates per firm and usually exists of a handful of key "must meet" and "should meet" criteria, which aligns with what Cooper proposes for the initial screening process also known as Gate 1 of the stage-gate process (Cooper, 1990). In the next phase, the organisation revises its focus of interest and challenges to decide whether to kill/stop or continue the current projects and convert the new ideas to projects and start developing them. **(4)** The users can follow these projects in EasyCrit **(5)** and post and share improvements to the projects while following their development. Periodically the ideas and projects can be made visual in charts and their contribution (success) to the company's strategy and other financial benefits can be reported **(6)**. This allows for the identification of succes cases (i.e. financially good, strategic aligned) and "bad" cases for the purpose of learning. The process then starts again by revising the focus and creation of new challenges. The model incorporates a process of learning and utilises the successes and failures of previous innovation projects.

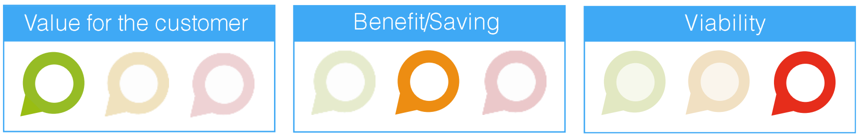


Figure 23 EasyCrit evaluation criteria example

The EasyCrit innovation management model shows similarities with the adapted Stage-Gate process introduced by Cooper (2014), illustrated as 'Stage-Gate Lite' in Appendix E: Stage-Gate development. Ideas are managed through a funnel of four stages and get voted upon in three gates (decision points). **(1)** Once an idea draft is finished it is thrown into the funnel. After which the social support group (the whole organisation, i.e. the departments and executive teams) improve the ideas and vote for the best ideas *(Gate 1)*. The top voted ideas make it through the first gate. **(2)** In the second stage, the committee reviews the voting from stage 1 and the portfolio of ideas. The top ideas get voted upon by the innovation committee *(Gate 2)*. The committee gets access to the full list of ideas and can also appoint a "favourite", even though the idea did not make it through gate one. **(3)** The ideas that make it through the second gate become "candidates" and await more information and a business plan before the innovation committee votes to create a project from the chosen candidates *(Gate 3),* based on the on the business plan and the simple evaluation presented in Figure 23. **(4)** In the last stage, the committee starts investing and developing the concept into projects. Ideas that don't make it through get "archived" if perceived as bad ideas or "frozen" if the timing is not right to develop the concept.

The EasyCrit model possesses several weaknesses as an innovation management tool when being compared to theory. The following weaknesses were identified, which have a negative impact on the innovation process. **(1)** The model lacks clear gate deliverables, i.e. what information must be provided to enable decision-making and its possible sources. Making it unclear for the decision makers how to approach the decision and to structure the process (Cooper & Edgett, 2012). **(2)** The innovation decisions are being made based on ordinal subjective ratings along three criteria instead of fact-based and objectified decision-making. This method might suffice in the idea screening process (according to the current users and Cooper (1990)), but deciding whether to start investing and developing a project requires clear criteria and kpi's (key performance indicators) to help objectify and justify the decisions (Cooper & Edgett, 2012). **(3)** It remains unclear when to kill or further develop a project. These criteria are not defined, written down and visible to everyone. The process outputs several visual charts and graphs and financial numbers, but fails to illustrate how projects are ranked or how "good" projects should look like. **(4)** Although customizable, the tool remains unadaptable to the innovation environment but needs to be tailored to the user's context (innovation process and structure). The model possesses static gates, does not include any feedback loops (Cooper, 2014b), and fails to highlight the knowledge and information exchanges and linkages happening within the process. **(5)** The innovation process is presented as a sequential process, in which portfolio management activities and innovation management activities are illustrated as steps that follow each other. In reality, these processes occur parallel to each other (Alemán et al., 2015; Cooper et al., 2001b) and the different activities are not necessarily dependent on each other (e.g. the ideation process can also happen without the strategy or challenges being defined, but focussed on client needs) (Berkhout et al., 2006) (see Sections 3.1.2 & 3.3.3).

The EasyCrit tool possesses a handful of strengths as an ideation tool and support system in general, when compared to what theory proposes. **(1)** The model utilises distributed voting schemes. This method allows for the whole organisation to vote for ideas and serves as a supplement to executive idea evaluation. This ensures that unselected executive ideas that rank high for employees may be given a second change before getting discarded and conversely. The reasoning behind it is that employee ratings offer decision-makers a valuable contribution to a more nuanced picture when they are deciding what ideas should be further developed (Onarheim & Christensen, 2012). **(2)** The model allows for user customization and tailoring to the firm's preferences (in terms of criteria, parameters, graphs, and labels) and focusses on reaching strategic and corporate goals. It forces senior management to think about their strategic goals up-front and translate those to 'challenges'. Including strategic alignment upfront in the innovation project development process helps to avoid unnecessary expenditure (Coulon et al., 2009). Barczak et al. (2009) illustrate that the best performing organisations have a higher number of idea generation activities that are strategy driven to fill specific gaps in the product line or extend the product line into specific strategically developed directions. Ideas that are more closely aligned to the firm's strategy are more likely to lead to a project that gets commercialized and is successful in the marketplace (Barczak et al., 2009). **(3)** Because the model operates through an online interface it can be easily accessed anywhere and tested beforehand by firms. This allows organisations to utilise input from external firms or employees that are not geographically close for the ideation process. The advantages of using partners and vendors as a source of ideas has proven effective (Cooper & Edgett, 2008). The advantages this method brings are that vendors and partners bring their technical capabilities to the table that may be beyond the internal scope of expertise and thus result in more creative and novel ideas. **(4)** The model involves the 'whole' organisation in the idea generation process, i.e. the different departments and executives. This has two positive effects: firstly, it increases the chance of creating original proposals (Bessant, 2003), and secondly it provides the opportunity to achieve more engagement and broader feedback from a more diverse set of business functions early to identify potential implementation challenges. As was earlier highlighted in Section 3.2.2, companies that can involve the entire organisation in the ideation process, have the strongest prediction power in idea generation and assessment. **(5)** The model illustrates the feedback loop in which the gained knowledge, information and experience from previous projects are utilised to help revise and define the strategy and generate new ideas (i.e. for new innovation projects). By providing the users the ability to follow innovation projects throughout their existance and alow the users to comment and share insights, the innovation projects can be cintinuously iterated upon and improved. Learning happens throughout the innovation process, where ideas build on ideas and new knowledge & information allow for new insights and improvements. The innovation process, therefore is not sequential (Berkhout et al., 2010), but the process should allow for feedback loops to revise the design and improve the development (Cooper, 2014a). (see Sections 3.1.2 & 3.2.2). **(6)** Innovation concepts often get killed too early by decision-makers (Section 3.2.2). Ideas and innovation projects that do not get selected or stopped, either get archived or temporarly frozen. This allows decision-makers to return to the ideas and utilise them if needed in a later stage or sell and license them to external parties to obtain their maximum potential.

In conclusion, the EasyCrit model would not serve well for the innovation management process. The model does not provide a solution for the issues surrounding the Stage-Gate model and discussed in Section 3.2.2. The solution, however, possesses several benefits for "fuzzy front end" of the innovation process, i.e. all activities from the search for new opportunities through the formation of an idea to the development of a precise concept (Trott, 2012 p.434). Users of the Stage-Gate process (Cooper, 1990) might know the process as the idea generation stage and idea screening gate (Section 3.2.2).

The need for a proper idea management process was emphasised by Barczak et al. (2009). Firms seem to be least effective in the idea management process. The benefits would help firms to structure their idea generation process and increase the likelihood that the ideas generated are aligned with the strategy, which leads to more successful products in the marketplace (Barczak et al., 2009). The easy and soft evaluation criteria during the idea screening process was perceived positively by the user base and sufficed in most cases. The ability to customize the model and involvement of the whole organisation to participate in the ideation and idea screening process allowed for a stronger involvement, and more novel and creative ideas.

4.3 INTERVIEWS

The relevance of the research effort is with respect to the practitioners who plan, manage, design, implement, operate, and evaluate information systems. To be relevant to this community, the design-science research must address the problems faced and the opportunities granted by the interaction of people, organisations, and information technology (Hevner et al., 2004). To gain an understanding of the practical relevance, a qualitative method (case-study) was used to enhance the knowledge of this domain. Qualitative data was collected by conducting a few open unstructured and eight semi-structured interviews (Appendix D: Interview list). For legal reasons, the group sample had to be limited to the client base of the two commissioning organisations rather than to a completely random one. This Section will introduce several design requirements for the envisioned IPM tool (Section 1.5).

The case studies conducted during this research project (Table 8) served multiple goals and helped to gain better insight into the issues affecting these stakeholders in their innovation management practices. **(1)** The first goal was to obtain feedback and insights on the design requirements of the IPM tool. The model was iteratively demonstrated to lead-users (Section 3.1.2), through simulation methods, evaluated, and further improved through the in-depth feedback this qualitative method (case study methodology) brings along. Followed by a validation of the feedback through theory. In between the case studies, the design was also frequently analysed and improved through internal meetings (at the commissioning firms) with several innovation experts, and through the continuous search in the knowledge base for validation and improvement of the gathered data. These case studies are therefore labelled as Lead-User case studies (LU). The case studies were focussed on obtaining feedback and insights on the IPM tool to help improve the model, and gain a better understanding of the organisation's key performance indicators, evaluation methods, and decision-making surrounding the innovation process **(2)** The second type of case studies, were performed to better understand the current innovation practices, key performance indicators, evaluation methods, and decision-making processes within the application domain. The case studies are therefore exploratory in nature and are labelled as Exploratory case studies (E). While the other case studies (LU) also involved the exploration of the current practical environment and its innovation practices, these case studies (E) were solely exploratory. The interviews were focussed more on the currently deployed innovation management practices, the organisation's (open) innovation structure and decision-making processes, the utilised innovation decision support systems and reasoning for their utilisation, the knowledge on innovation portfolio management, and how knowledge revolving innovation is dispersed throughout the organisation (i.e. collaboration on innovation projects). These case studies were performed in a later stage than the first type of case studies (LU), and served to complement the development of the innovation decision support framework with insights from the application domain (following the steps of Figure 5 in Section 2.4 towards an "enriched design" of the artifacts).

By using a qualitative research strategy, a general idea of the object as a whole is obtained, whereas a survey only reaches a certain aspect of the research object. The holistic quality is obtained using qualitative, semi-structured ways of gathering data. Several authors argued that the case study method is the preferred method of investigation for applied disciplines, such as Information Systems (Gregor, 2006; Iivari, Hirschheim, & Klein, 1998). The case study does not require much pre-structuring and thus the research will be much more flexible. McCracken (1988) also argued that "to get a better understanding of the social science within the company an interview is a must".

Organisation	Date	Type
INDO	02-11-2015	LU
Zanini	12-11-2015	LU
FCB	26-11-2015	LU
External expert 1	10-12-2015	LU
Shell	28-01-2016	E
IDIADA	02-02-2016	LU
INDRA	02-02-2016	E
External expert 2	03-02-2016	E
RWS	22-02-2016	E
RWS 2	01-03-2016	E

Table 8 Case study types

To carry out the investigations in the relevant context without performing as "participant observers" the role of an embedded researcher was taken (Reiter-Theil, 2004). This method proposes that knowledge that is collected and created 'on the ground', through daily interaction and negotiation with practitioners, managers and service users, will probably provide better insight into the issues affecting these stakeholders and be more relevant to the local context and, therefore, more easily incorporated into changes in practice (aligning with the design science research guidelines proposed by Hevner et al. in Section 2.2). The reason for this is that the coproduction of knowledge between the embedded researcher and the local teams can lead to greater "ownership" of the research findings in the organisation, which could lead to a smoother incorporation of the changes in practice (Vindrola-Padros, Pape, Utley, & Fulop, 2016).

Within the commissioning firms, regular internal meetings were held with several consultants and executives for iterative feedback on the requirements of the IPM tool (Sections 1.3 & 1.5). Notes were made after each meeting and used to further improve the tool's design, gain direction in the theoretical domain, and prepare for the next meeting.

To help generalize the findings of the research to a certain extent, the data was collected from a diverse sample set. The diversity served to reduce the informant bias, and enhanced the construct validity (Maxwell, 2012). Diversity was based on; Size (*Big & Small with regards to revenue & number of employees),* Type of innovation (*Process & Product innovation),* Industry (*broad range of industries),* and Geographical Location (*The Netherlands & Spain)*, as is illustrated in Appendix D: Interview list.

The set of organisations interviewed (Table 9) provided a clearer image in how these firms differentiated in their innovation management practices and how certain firms could implement several approaches simultaneously. The case studies provided the insights to dive deeper into more critical components of the management process and extract some key requirements that weren't clear in literature. These insights could have only come to light through the intervention of an innovation decision support system. The organisations also helped to provide a diverse set of evaluation criteria (Table 9). These criteria were considered in the development of the IPM tool, which will be further elaborated in the next Chapter 5 (Section 5.1).

Company	Approach	Most important criteria	Innovation Management tool	Innovation type
INDO	Top-down	Payback rate, profitability	Excel	Product
FCB	Bottom-up	Cost reduction, team alignment	Excel + EasyCrit	Service
Shell	Bottom-up	Strategic alignment, networking, payback rate, push technology advancement	Several	Service
Zanini	Bottom-up	Strategic alignment, image	Excel + EasyCrit	Product
Idiada	Top-down + Bottom-up	Feasibility, client needs, strategic alignment	EasyCrit	Service
Indra	Top-down + Bottom-up	Viability (tech. & commercial), client needs, novelty	None	Service
RWS	Bottom-up + Top-down	Cost reduction, reliability, sustainability	None	Service

Table 9 Interviewed organisations and their innovation approaches and KPI's

The small sample size (*n*=8), and broad diversity of size, type of innovation, industry and geographical location did not allow for the identification of industry standards. Beside the eight interviews done with firms, two other semi-structured interviews were conducted with external experts on the dimensions of this research (see Appendix D: Interview list). The interviews were conducted in English, Dutch or Spanish depending on the interviewee.

Prior to each interview, the interviewees were informed about the purpose of the research (i.e. designing an innovation portfolio management model and a support framework to help position the model in current innovation management practices). Some meetings (the LU case studies) were done formally, i.e. in the name of the commissioning firms, with Power Point presentations providing details on the project assumptions and progress. While other meetings (the E case studies) were done in a more informal manner, i.e. as a student from the TUDelft.

Case studies were performed following triangulation methods. This approach encourages the researcher to collect information from multiple sources. The use of evidence from multiple sources helps to increase confidence for the case study findings to be accurately and was proven to be higher in terms of overall quality. This approach would result in a better construct validity of the qualitative data provided (Yin, 2013). Several sources of data were used, such as field notes from informal interviews, lectures seminars, expert group meetings, newspaper articles, internet mail lists and colleagues in the commissioning firms (Charmaz, 2014). The analysed data from the case studies were jointly collected with documents, notes from expert group meetings, seminars, colleagues and observations. The information helped to define what kind of data had to be collected in the next interview and from which srouce. This iterative way of data collection helped to enhance the efficiency, depth and quality of the data collection (Charmaz, 2014; Ralph, Birks, & Chapman, 2014).

To avoid misdirection (i.e. deviation from the study purpose) in the case studies, case study protocols (i.e. an interview guide) were used to carry out the case studies and helped steer the case studies occasionally. According to Yin (2013), using case study protocols when performing case studies with multiple sources of evidence, is not only desirable but essential to increase the study's reliability.

4.3.1 CASE STUDY INSIGHTS

This Section will provide some insights received from case studies that were conducted during this research project. The first case study was conducted with the chief innovation officer of INDO (also a part-time professor on Innovation Management at the Universitat Pompeu Fabra). The case study was focussed on receiving feedback on the initial design requirements for the IPM tool (see section 4.3), and to obtain some insights for the development of innovation decision support systems. The feedback received was mostly on practical implications and issues that need to be considered during the implementation of the IPM tool. INDO develops and markets ophthalmic lenses for several industries. In the past, they were developing a similar innovation portfolio management tool (with MS Excel) and recognized that the problem in the firm was not the tool itself, but the commitment of the company towards the methodology and structuring the innovation process. The possession of a tool would be very helpful if the innovation decision-making process is structured. However, if the decision-making process is not structured, then it would only be a matter of who can sell their idea the best and influence others. In this case (when there is no methodology), there is no room for a tool. Tidd, Bessant, & Pavitt (1997 p.13) also argued that the innovation process needs to be understood and managed, so that innovation success can be understood and little gets left to chance. Therefore, the innovation process must be semi-structured and not left fully dependable on intuition and chance. Another issue that was pointed out was the inconsistency in the methodologies of the several departments. This is an important issue, because otherwise there would be no consistency in the evaluation of projects and subjective reasoning would rule. This issue has been illustrated earlier, in Section 3.2.1, as "over-the-wall" models. In these models, each department would only carry out their task and departments don't overlap leading to no consensus in the decision-making process (Trott, 2012 p.438). E.g. Incremental innovation projects don't have a lot a lot of uncertainty, their main problem is that the resources they have are limited. This would often result in a conflict between the sales people and the technical people. Sales people tend to mix the nice-to-have (NH) and must-have (MH) projects and as a result lose sight of the portfolio balance. This issue is illustrated in several papers, including the early Stage-Gate introduction (Cooper, 1990), where Cooper suggests to place decision points where projects are subjected to should meet and must meet criteria.

The second case study was exploratory in nature and was performed with a freelance innovation consultant for the TU Delft (External Expert 2, Appendix , Table 8). The expert explained that most tools he used as an innovation manager, would solely focus on the internal technology development. He then continued to argue that it is critical to address the concept of alliances in an innovation portfolio management tool. The methodology needs to introduce and facilitate external stakeholders in the innovation process. The tool can then be used beforehand to talk to clients and the Sales department and ask how the technology would be received and if it fits the client needs. These linkages would allow for the following potential advantages. **(1)** The including of customers in the decision-making process before making decisions to continue or kill projects. As was previously illustrated in Sections 3.1.2 and 3.4.3, these linkages are important and provide several benefits (Von Hippel, 1986). They provide the firm with clear insights of the market needs and wants and what kind of impact or effect the technology would have on their business in an early stage. **(2)** Collaborating with universities to share the weight of long-term projects with organisations. These collaborations were previously highlighted in Chapter 3.4.4 whereas university departments work closely with local firms on a wide variety of research projects with a common interest. The absence of a legal entity allows for more flexibility and provides the opportunity to extend the cooperation for many years. **(3)** including other organisations based on established relationships to reduce the costs and share responsibility. In these cases, it is important that the innovation partner knows the strategy of the other firm and thus their strategy and in-house technologies should be shared. Bertkhout, Hartmann and Trott (2010) also illustrate that thoughts, potential ideas, technologies and views are shared and exchanged through social interaction to facilitate innovation.

The expert notes that he has seen a lot of good tools failed, because they did not account for the customer's internal innovation practices (such as other deployed solutions, the organisation's structure, and decision-making process). This critical aspect of integrity was illustrated by Phaal et al. (2006) and already highlighted in Section 3.4.1 as a design requirement. The tools should work together and link to the innovation practices and tools already deployed in the business.

"The tool is an important contribution to the decision-making process. However, the decision-making process is even more important than the tool itself, and thus the tool must fit within the customer's innovation decision-making process."

External expert 2

The last case study was performed at the Ministry of Infrastructure and Environment; Rijkswaterstaat (RWS). The organisation does not develop new products or technologies themselves, but takes up the role as lead-user (Section 3.1.2). The Ministry stimulates and challenges the market to develop innovations and offers to test, evaluate, help develop, and implement the innovations. The internal focus in the organisation lies more on how they can reach their goals by means of innovations. The innovation selection process depends more on the problems that are present and thus the list of available innovations is linked with problems/projects where they can serve as solutions. The goal of innovation is to make projects cheaper, more sustainable, safer, and deliver more functionality.

The ministry finds itself in the tough situation where it is forced to innovate, because the sea level is rising and it is impossible to renovate the artworks and maintain everything with the current budgets. Almost all dry and wet artworks were built after the world war and have reached their lifespan. However, not everyone in the organisation has realized that yet, because the employees are not held responsible for the implementation of innovations but for the reliability and budget restrictions of projects. This long-term neglect might lead to budget issues in the future and the loss of valuable pieces of historical artworks.

Two innovation managers were interviewed separately. The first interviewee was from the "Innovation and Market" (I&M) department and the second from the Corporate Innovation Programme (CIP). This programme defines what kind of innovations RWS needs and the I&M department tries to link innovations to those needs. One of the challenges they are facing was the process of innovation focussed procurement. One can have an innovation process, but if the production process and innovation process are not connected, the innovations will either never be done or very late or bad. "Innovations get tested and validated, but then what? How does one make sure the innovation will be implemented?" This was the main challenge they were facing. Most project leaders don't know what kind of innovations are available and therefore cannot implement them. Even though this issue is more project management related, it still serves as a critical barrier for innovation. Since many innovations are not considered, they don't get tested and validated, resulting in the killing of potential innovation projects because of budget restrictions. Therefore, awareness needs to be created among the employees of the available (innovative) solutions.

The department also experiences trouble regarding the innovation decision-making process, specifically the ownership of innovations. This is because there is no clear process or structure in the decision-making process yet. The organisation is too big and has too many heads for it. There are too many discussions involving a big number of people that possess counterforce (blocking power), but a low number with the decision-making power to initiate projects. This also accounts for the idea corporation, which entails a desk where everyone (all employees) can hand in their ideas. The problem is that even if some ideas would be perceived as good, it would be hard to find someone in the organisation that wants to continue with the idea. This is because they either think it has a lot of risks or because the idea was "Not Invented Here". It is hard to create ownership of the ideas when they come from the market (external to the organisation). The ideal situation would be one where these ideas would be co-developed, with the idea owners and external parties, to create more ownership for the employees within RWS (by including them from the start towards solving these challenges).

> "Ideally you would have a map of all the innovations so you can easily decide where and when you can implement certain innovations and easily find an investor for it. This is an ideal world that does not exist at RWS. Innovation happens a lot everywhere in the firm, and it should it be that way. If it would be organized that tightly you would kill all the energy of innovation."
>
> Innovation Manager RWS

Figure 24 shows the innovation process of RWS. The process is strategically-oriented, since it usually starts with a predefined challenge/problem that needs to be resolved. The process utilises external ideation and co-development of the solution with external parties, and helps RWS to take on the role of lead-user (Section 3.1.2).

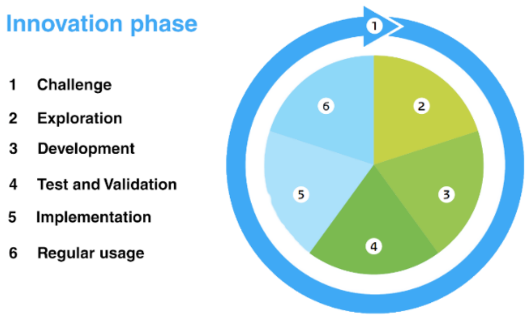


Figure 24 RWS innovation phases (Rijkswaterstaat, 2016)

Innovation portfolio management helps to map all innovations and link the technological developments. This could benefit RWS towards the development of a solution for their innovation problem, i.e. the invisibility of innovation projects and the lack of a method to recognize and link developments to other projects. The fact remains that other companies are held accountable for their new products and RWS is held accountable for reliability. "No one will get any stomach pain, because he/she is not utilizing innovations. If the project is within the budget and works, then everyone would be satisfied" (Innovation manager RWS). The organisation needs individuals with decision-making power to take on the role as entrepreneurs and make sure innovations happen (Berkhout et al., 2011).

All the case studies highlighted an important issue surrounding innovation portfolio management present in the organisations (see Section 1.2): It was unclear how the innovation portfolio management process relates to the current innovation management practices and models. I.e. how the process differs from the other innovation management methods (e.g. what additional information is needed to perform the process), and when the innovation portfolio management process needs to be performed or considered. For which this research hopes to contribute towards a solution in the form of an innovation support framework, which will be further elaborated in Chapter 5.

4.4 CONCLUSION

> *SRQ2: What are the relevant requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?*

The Chapter introduces several design requirements that, together with the requirements obtained from the theoretical domain in Chapter 3, support the development of the research artifacts (Section 1.3). The list of design requirements from Chapter 4, derived through case studies, are illustrated in Table 10. Due to budget restrictions design requirements P1, P2, P3, P4, P5, P6, P21, P22, and P23 serve as a basis for the concept design of the IPM tool. The concept design can be further improved as a decision support system through design requirements P7, P13, P14, P17, P20, and P19. These requirements complement the IPM tool by pointing out and visualising the risks and benefit of possible scenarios based on gathered data and information internally and externally to the organisation. The other requirements highlight activities that need to be considered in the innovation support framework.

Design requirements obtained from case studies		Source
P1	The model must include methods for remote participation in the innovation portfolio management process.	External Expert 1 **Section 4.1**
P2	Lead-users should be involved in the development (e.g. through toolkits)	External Expert 1 **Section 4.1**
P3	Innovation portfolio methods must be interactive (i.e. changes should be instantly visible), fast and able to display a number relevant data without complexifying the visuals.	External Expert 1 **Section 4.1**
P4	Avoid financial methods	External Expert 1 **Section 4.1**
P5	Focus on introducing Strategic methods	External Expert 1 **Section 4.1**
P6	The IPM model and methods must be customizable to better fit the user's needs and environment without the need for external involvement. The users must be able to adapt the model for a better fit with their internal structure and processes, and the dynamic external environment.	External Expert 1 **Section 4.1**
P7	The innovation management model must be capable of storing and sharing (of required) knowledge and information. This includes the identity of internal and external stakeholders, their roles, and their contribution	External Expert 1 **Section 4.1**
P8	Define organisation strategy (focus) up-front and revise when needed	Critflow **Section 4.2**
P9	Translate strategy to strategic and corporate goals (challenges) to help steer ideation.	Critflow **Section 4.2**
P10	Allow for executives to pull (unselected) ideas through the voting process to help reach portfolio goals.	Critflow **Section 4.2**
P11	Allow for the involvement of the whole organisation in the generation of ideas and screening of ideas, to create more novel and creative ideas, and reach more engagement from employees.	Critflow **Section 4.2**
P12	Projects must be followed throughout their existance to adapt to new internal or external insights, knowledge and information.	Critflow **Section 4.2**
P13	The knowledge and information gained through the innovation must be stored so that it can be accessed and utilised for future innovations.	Critflow **Section 4.2**

P14	Periodically the ideas and projects must be analysed and made visual in charts to help decision-makers identify their key performance indicators, such as the strategic alignment or financial benefits they bring, and help keep the portfolio balanced.	Critflow **Section 4.2**
P15	Ideas that don't get selected must either get archived or frozen to be utilised another time or in different manners (e.g. through licensing or sale).	Critflow **Section 4.2**
P16	Customers must be included in the innovation decision-making process, before making decision to continue or kill projects.	External Expert 2 **Section 4.3.1**
P17	The possibility and effect of sharing risks with external partners for long-term innovation projects need to be addressed.	External Expert 2 **Section 4.3.1**
P18	Address the important presence of established relationships and the need to share in-house technologies and strategies.	External Expert 2 **Section 4.3.1**
P19	Incorporate the mapping and linking of innovation portfolios with their technologies (technology mapping) to help identify and utilise innovations.	RWS **Section 4.3.1**
P20	Incorporate intelligence in the decision support system to reduce the resource intensity of the model	External Expert 2 **Section 4.3.1**
P21	There should be a simple estimation for future income, e.g. NPV	External Expert 1 **Section 4.3.1**
P22	When using portfolio scoring models, introduce four options. Since most users are uncertain, they tend to choose the middle option leading to invaluable results	External Expert 1 **Section 4.3.1**
P23	Incorporate a method that allows for innovation project selection based on budget restrictions (e.g. Bang-for-Buck)	Zanini **Section 4.3.1**

Table 10 Design requirements derived from the application domain

> *SRQ3: To what extent do the currently employed solutions at the commissioning organisations, meet the identified requirements?*

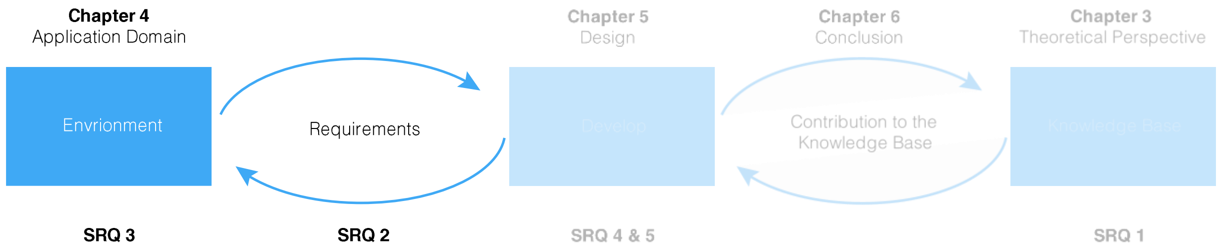
The Chapter started (Section 4.1) by analysing the current solutions of B&C (the Provatool) and relating it to the theoretical domain. The solution fails on many levels. It lacks the ability to adapt to the user's innovation context, i.e. the methodology could not be adjusted. The tool does not allow for any customization by the user, remote access to the solution, and neglects the external influences on the innovation process and the many linkages to external sources of information and knowledge.

However, the solution helps to illustrate several design requirements that were perceived as positively associated with the performance of the innovation portfolio management process. The following examples were introduced. The importance of remote participation for the innovation decision-making process. Lead-user involvement for the development of an innovation decision support system (Section 3.4.5). The focus on strategic portfolio methods, and avoidance of financial portfolio methods. These insights helped to define design requirements (Section 4.1) that serve as the basis for the IPM tool (Section 1.3).

The current solution of Critflow (EasyCrit) was analysed and related to the theoretical domain (Section 4.2). The solution failed on many levels of innovation management, but also provided relevant insights. The innovation management solution possessed several issues. The model, the solution utilises, is linear and sequential with several decision points. It shows innovation portfolio management practices and innovation management practices in a sequential manner. However, these activities occur parallel to each other with many feedback loops (Section 3.3.4). The model does not illustrate what kind of information is needed and where the information might origin from. The solution utilises subjective ratings along three criteria to make most of its project selection decisions, which is not enough to properly objectify and justify the decisions.

However, the solution highlighted several practices that coincide with what theory proposes, such as the need to define the organisation's strategy up-front to perform innovation portfolio management. The incorporation of innovation portfolio management in the idea management process to help provide direction in the idea generation process and pull ideas through the idea screening process (Section 3.3.4). As well as incorporating the whole organisation in the idea generation and idea screening process to obtain more novel and creative ideas and a stronger involvement in the innovation process. The solution also showed the importance of storing ideas and projects, whether they are killed or successful, so that this knowledge can be utilised in future developments. These insights introduced several design requirements that are used to help develop the innovation support framework (Section 1.3).

Sub-research questions 2 and 3 have been answered (SRQ2 partly). The knowledge they bring, together with the knowledge obtained from the theoretical domain (Chapter 3), is utilised in the next Chapter to develop the research artifacts.



5 DESIGN

The insights and knowledge from Chapters 3 and 4 are used in this Design Chapter to help develop the research artifacts and answer the last two research questions. The Chapter develops the following two artifacts: (1) the design requirements for an innovation portfolio management tool, and (2) an innovation support framework to support the innovation management processes (see Section 1.3).

The Chapter also helps to answers the following two research questions:

> *SRQ4: What are the relevant criteria for an innovation portfolio management tool, that can serve as a basis for future co-development with lead-users in the application domain?*
>
> *SRQ5: What are the relevant criteria for an innovation support framework, that can adapt to the user's context and methodology and help position and integrate the innovation portfolio management model in current innovation management practices?*

The Chapter starts with the development of the IPM model in the form of a tool. Followed by an elaboration on the building blocks of the innovation support framework (Section 1.5). The elaboration starts explaining the idea management process (Section 5.2) and continuing towards the development process (Section 5.3). The Chapter continues by illustrating the overall presence of the innovation portfolio management process and the strategy (Section 5.4). Section 5.5 shows the final model, and highlights the importance of the external environment. The last Section discusses several solutions to help reach the research objective in practice, by illustrating the benefits of decision support systems for the innovation support framework (Section 5.6). The design requirements utilised in the Chapter, will be referred to as **T**- and **P**-numbers and are highlighted in **red**.

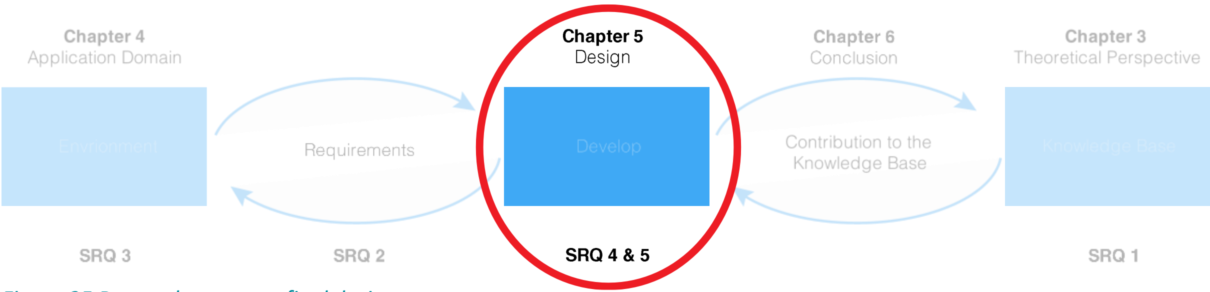


Figure 25 Research structure final design

5.1 IPM TOOL

Following Hevner's guidelines (see Section 2.2), the design research process involves the demonstration of the design artifact through evaluation methods, and the application of rigorous methods in both construction and evaluation of the design artifact. The knowledge base (Chapter 3) together with internal insights (at the commissioning firms), the application domain (Chapter 4) and the existing solution (Provatool, Section 4.1) allowed for the design requirements of the first design concept for the IPM tool (Section 1.4).

Section 4.3 illustrated the demonstration and evaluation of the model using qualitative methods, such as case studies and frequent meetings with internal innovation experts. These activities correspond with the iterations illustrated in the model of Peffers et al. as steps 3-5 (Figure 4, Section 2.3). The result is the innovation portfolio management model illustrated in this Section.

Chapter 3 highlighted several design requirements derived from the Theoretical domain that served as the starting point for the concepts design of the IPM tool (Table 11). These requirements were agreed upon by internal consultants at the commissioning firms.

No	Design requirement derived from Theoretical domain	Design requirement for artifact	Source
T13	Innovation portfolio management must include more than one innovation portfolio method with an average between two and three methods. These methods should complement each other.	Include two to- four complementing innovation portfolio methods in the IPM tool (see Section 1.5).	(Cooper et al., 2000) **Section 3.3.3**
T14	The combination of innovation portfolio methods jointly must address all four major innovation portfolio goals.	Incorporate at least two out of the three innovation portfolio methods recognized by Coulon to do so (bubble diagrams, roadmaps, scoring models).	(Coulon et al., 2009) **Section 3.3.3**
T15	Financial portfolio methods perform the worst in terms of innovation performance, the focus should lie more on strategic portfolio methods.	Focus on strategic portfolio methods, rather than on financial portfolio methods.	(Cooper et al., 1999) **Section 3.3.3**
T16	The combination of innovation portfolio methods must be customizable (i.e. choosing methods, parameters, criteria, weights, labels) to better suit the context surrounding the innovation.	Address the ability of customization, by the user, within the innovation portfolio methods.	(Cooper et al., 2001b; Coulon et al., 2009; Phaal et al., 2006, 2004) **Section 3.3.3**

Table 11 Design requirements for innovation portfolio management tool from Theoretical domain

Chapter 4 highlighted several requirements obtained from the Application domain that served as the starting point for the concept design of the IPM tool (Table 12).

No	Design requirements obtained from case studies	Source
P1	The model must include methods for remote participation in the innovation portfolio management process.	External Expert 1 **Section 4.1**
P2	Lead-users should be involved in the development (e.g. through toolkits)	External Expert 1 **Section 4.1**
P3	Innovation portfolio methods must be interactive (i.e. changes should be instantly visible), fast and able to display a number relevant data without complexifying the visuals.	External Expert 1 **Section 4.1**
P4	Avoid financial methods	External Expert 1 **Section 4.1**
P5	Focus on introducing Strategic methods	External Expert 1 **Section 4.1**
P6	The IPM model and methods must be customizable to better fit the user's needs and environment without the need for external involvement. The users must be able to adapt the model for a better fit with their internal structure and processes, and the dynamic external environment.	External Expert 1 **Section 4.1**
P21	Ideas that don't get selected must either get archived or frozen to be utilised another time or in different manners (e.g. through licensing or sale).	Critflow **Section 4.2**
P22	Customers must be included in the innovation decision-making process, before making decision to continue or kill projects.	External Expert 2 **Section 4.3.1**
P23	The possibility and effect of sharing risks with external partners for long-term innovation projects need to be addressed.	External Expert 2 **Section 4.3.1**

Table 12 Design requirements for innovation portfolio management tool from Application domain

The IPM tool consists of several portfolio methods (see Table 13). The following combination of models follow three theoretical design requirements; **T13, T14, T15** (Table 11), and four practical design requirements; **P4, P5, P21, P23** (Table 12).

Portfolio method	Purpose
Bubble diagrams	to help plot the innovation portfolio against several dimensions of interest.
Scoring models	to help rank the innovation projects
Bang-for-Buck	to complement the ranking method (score card), by introducing budget restrictions
NPV	to let decision-makers think about future income (some organisations prefer the using the term future "Reward")
Strategic buckets	to complement the other portfolio methods by illustrating the resource allocation and portfolio balance

Table 13 IPM tool portfolio methods (Section 3.3.3)

To achieve the requirements illustrated in the two tables (Table 11 & Table 12), the decision was made to incorporate the model as an additional module to the EasyCrit online solution (Section 4.2) illustrated in Appendix H: IPM tool digital interface. The EasyCrit tool brings along the ability for remote access and participation. This allows lead-users to utilise the IPM tool as a toolkit (Section 3.1.2) and help the commissioning organisations improve and develop the model. This also provides the users with the ability to customize the criteria, parameters, labels, type of graphs to better fit their internal innovation practices and avoid long forms with inapplicable criteria. Several authors also highlighted the concern when defining a model, that too long evaluation forms that are needed to be filled in for multiple projects would become a burden, leading to the model not being utilised (Bitman & Sharif, 2008; Cooper et al., 2001b; Coulon et al., 2009; Phaal et al., 2006). Bitman & Sharif (2008) propose the use of an electronic project evaluation form with all criteria from which a firm can eliminate the criteria it deems to be unnecessary. This online evaluation method adapts to match the selected criteria on the evaluation form, and allows its users to customize the evaluation methods remotely.

5.1.1 DEVELOPING A SCORING MODEL

When developing the Multi-criteria decision-analysis for the IPM tool (Section 3.4.4), the first two phases illustrated in the four-phased process of Wang et al. (2009) (Section 3.4.5), was internally used at the commissioning firms. The first phase of this model focusses on defining the decision goals, followed by the formulation of alternatives, selection of criteria, and assigning (normalized) scores to criteria. For the formulation of alternatives and criteria selection, several sources of information were used and accumulated to help converge the list into a smaller set (around 20). Sources in the theoretical domain (Cooper, 2013; Cooper & De Brentani, 1984; Cooper & Edgett, 2006; Cooper et al., 2001a), such as books and articles, and sources in the practical domain (Frost & Sullivan, 2010; Järrehult, 2014; Nagji & Tuff, 2012; Nauyalis, 2015; Planview®, 2012), such as prior case studies, seminars, webinars, internal documents, and the Provatool (4.1) were utilised.

The second phase involves determining the weights of the criteria. Weights are assigned to criteria to indicate the relative importance and impact of the criteria for the decision-making problem. In the case of the IPM tool, these weights were obtained through the agglomeration of feedback and insights from several innovation experts, and the existing solution, and decided upon together with the research project supervisors. A subjective weighting method was chosen, because it explains the evaluation clearly while the objectivity ones are relatively weak. Wang et al. (2009) highlight that using this method criteria weight's errors are unavoidable, and proposes a combination of objective and subjective weighing methods. The research scope did not allow for this combination, since not enough experts could be reached to perform a similarity (concordance) analysis. Additionally, there was insufficient initial data to calculate the objective weights of criteria. Future improvement of the design should include an integrated method of both objective and subjective weight criteria. Wang et al. highlight some example of objective weights methods in their paper (2009).

Among the subjective weighting methods proposed by Wang et al. (2009), the pair-wise comparison model was chosen together with the Analytic Hierarchy Process (AHP). The reason was the simplicity of the method, the amount of time it requires and existing knowledge and experience of the methodology within the commissioning firms. The method works as follows: Participants are presented with a worksheet and are asked to compare the importance of two criteria at a time. The results are combined by adding up the scores obtained by each criterion, when preferred to the criteria it is compared with. The results then get normalized to a total of 1.0. This weighting method helps users to compare each criterion against all the others, and to show the difference in importance between the criteria. The consistency of participants' preferences, however, cannot be checked in this model. Therefore, the pair-wise comparison method is complemented with the AHP process. The AHP process builds on the pair-wise comparison model and provides the possibility to check the consistency. Because individual judgments will never agree perfectly, the degree of consistency that is achieved in the pair-wise comparison is measured. The process synthesizes the judgments of the many participants to yield a set of overall priorities for the hierarchy.

The IPM tool evaluation method revolves around a set of open and closed questions (multiple choice). The open evaluation utilises a score-card. This scoring model ranks individual innovation projects on a specified set of criteria, whereby the criteria would have different weights (Section 3.3.3). The model turns qualitative assessments into quantitative evaluation to serve as the basis for innovation project decision-making. The resulting scorecard is highlighted in Table 14 and Table 15.

The outcome of the general fields are project labels and will only play a visual role in the portfolio analysis. The fields are mostly filled in by the innovation decision-makers, based on a first estimation (hunch) since information is lacking. The fields can be customized and filtered out if not needed.

General		**Project ID**	
		Project name	
		Description	
		Status *(active, on hold)*	
		Group (4/5 company specific clusters)	
		Project type *(new product, improvement, ongoing)*	
		Project responsible	
		Position *(of responsible)*	
		Expected development time *(time to launch)*	years
		Potential return on investment	€
		Total investment until launch	€

Table 14 IPM tool General input

Following the requirement **P22** (Table 12) (Section 4.3.1), the scoring model utilizes four variables (scoring options). The weights and criteria were internally decided upon, through iterative meetings with internal innovation experts of the commissioning firms.

Criteria	Criteria Weights	Factor	Factor Weights	Scoring options			
Technological risk	0.2	Technology newness	0.4	1	2	3	4
		Availability of skills and capabilities	0.1	1	2	3	4
		Phase of the project	0.2	1	2	3	4
		Technological uncertainty	0.2	1	2	3	4
		Regulatory/IPR/Social barriers	0.1	1	2	3	4
Market risk	0.8	Market newness	0.3	1	2	3	4
		Realistic competitive position on launch	0.2	1	2	3	4
		Level of competition	0.3	1	2	3	4
		Market openness to future entries	0.2	1	2	3	4
Technological attractiveness	0.3	Makes a step forward in your technology roadmap	0.3	1	2	3	4
		Makes use of previous steps in your technology roadmap	0.1	1	2	3	4
		Relevance of new technology	0.5	1	2	3	4
		Potential IPR position	0.1	1	2	3	4
Market attractiveness	0.7	Price/performance compared to competitors	0.2	1	2	3	4
		Sustainability of competitive advantage	0.4	1	2	3	4
		Foreseen market size on launch	0.1	1	2	3	4
		Growth potential of target market on launch	0.1	1	2	3	4
		In line with your market growth strategy	0.2	1	2	3	4
Strategic fit	1	Alignment of projects with business strategy	0.4	1	2	3	4
		Importance of project to the strategy	0.3	1	2	3	4
		Impact on business	0.2	1	2	3	4
		Platform for further growth	0.1	1	2	3	4

Table 15 IPM tool Criteria + weights

The innovation project's scores are made visual through several graphical representations, such as bubble diagrams, pie charts and other graphical visualizations (Figure 26). Using online interactive solutions (through EasyCrit), more information can be displayed in a more direct and interactive manner. This also helps to keep the tool's complexity to a minimum and certain data is only shown when needed (requested) **(P3)**. The bubble diagram allows for several parameters to be visualised and customized: Vertical axe, Horizontal axe, Inner bubble, Outer bubble, Colour of bubble, Colour of areas. Due to legal reasons, the fully integrated model (within EasyCrit) cannot be further illustrated.

The IPM tool (model) needs more iterations and feedback rounds, so that the model can be further improved (regarding the selection of portfolio methods, development of a general template of criteria, and selection of graphical representations). This general model serves to help innovating organisations to start thinking about the innovation portfolio management process, how they can be supported in this process, and how the process can fit with their current innovation practices.

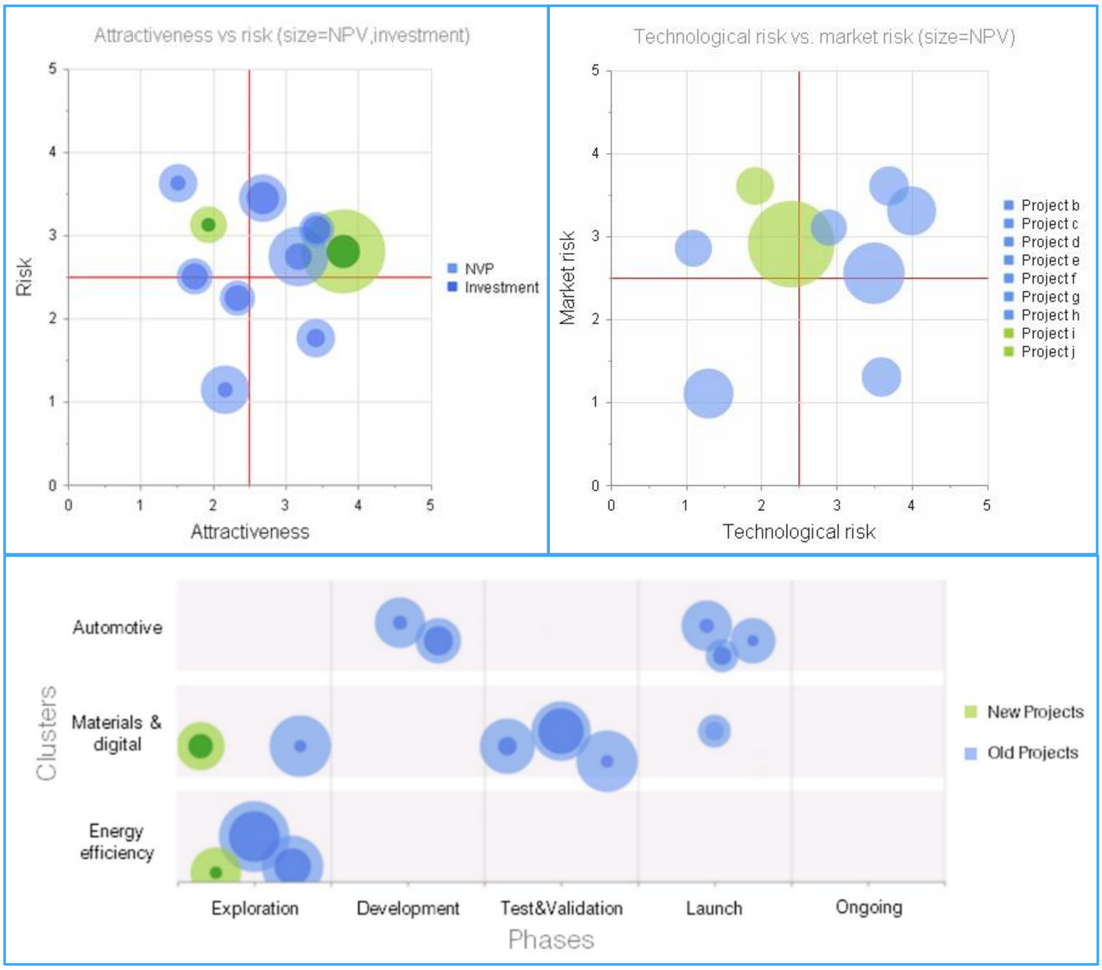


Figure 26 Bubble diagrams developed for the innovation portfolio management tool

As was highlighted in Section 4.3.1, several organisations have difficulty with the innovation portfolio management process, because they fail to identify how the process relates to other innovation management practices. I.e. how the process differs from the other innovation management methods (e.g. what additional information is needed to perform the process), and when the innovation portfolio management process needs to be performed or considered. To contribute towards a solution for this issue, an innovation support framework is developed (Section 1.5). The following sections will illustrate the development of the building blocks of the innovation support framework.

5.2 Idea Management

As was highlighted in Section 3.1.1, "Innovation is the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product, process or service". The process was split in three activities: **(1)** Idea management, **(2)** Development, **(3)** Launch & Follow, as illustrated in Figure 27. The (blue) arrows illustrate decisions made by innovation decision makers to move into another stage and start the activities that correspond with the stage. This section will elaborate on the idea management activity.

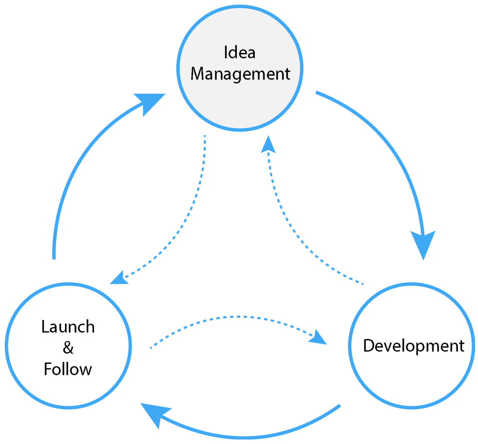


Figure 27 The three main activities of the innovation process

The idea management model exists of many feedback loops and iterations happening in the idea management process. Chapters 3 and 4 highlighted several information and knowledge linkages to the idea management process within the innovation process that resulted in requirements. A model was created to illustrate these linkages. First the building blocks for this model will be elaborated and lastly the Section ends with the overall idea management model.

The idea management process entails the ideation process, and idea screening process. Ideas can get improved and socially ranked by employees. And the innovation committee can also bring ideas to the table and discuss them even if they were not ranked in the top of the voting process. By incorporating the whole firm in the ideation process (and external partners) the diversity of ideas and level of idea ownership felt by the employees would rise (**T6, P11**) (Section 3.2.2).

Section 3.2.2 illustrated that the idea management process is best performed by incorporating the whole organisation to generate, improve and vote for the ideas. Including the whole firm in the generation of ideas is positive for the novelty and creativity of the idea generation process. However, involving the whole firm to vote and improve the ideas, might not serve all organisations. Some organisations innovate internally and try to hide their developments (e.g. Apple (Fox, 2013)). the leakage of sensitive information to competitors could lead to more competition and even the loss of the firm's competitive advantage (Section 3.4.3). Therefore, the idea management process needs to be customized to best serve the organisation's internal practices.

Figure 28 illustrates several examples of information and knowledge linkages between the external environment and idea management. Through **collaboration** and the share of knowledge, skills, technologies, and the strategic goals, organisations (and individuals) can assist each other and generate more novel and creative ideas (Berkhout et al., 2006). This could happen for cases, such as to set an industry standard or ideate together to solve mutual challenges (e.g. environmental issues) (Section 3.4.3). Involving the **suppliers** can also help to bring ideas to light that provide more cost-benefits because of a better fit between the two stakeholders (Section 3.4.3). The **customer**'s involvement in the idea generation and development process, helps to develop a product that best meets the customer's needs (**T1**). As well as in the idea screening process to help vote for the best ideas, before killing ideas (**P16**).

The customer, however, does not always know what he or she wants or needs. The soft-science can help to highlight new (predictive) insights into **market transitions** and the dynamics of society's needs and concerns (Berkhout et al., 2006). These insights help to determine the appropriate time for organisations to perform innovations (**T1**).

New ideas could involve new functional requirements, which can drive new technological research and scientific exploration. By sharing these requirements, organisations can **pull functions** and facilitate the technical research to create novel technologies. It is important for organisations to facilitate new technological research and be aware of new technological research in the environment, so that scientists and engineers constantly inspire each other (Berkhout et al., 2006).

Berkhout et al. (2006) illustrated that success in the innovation process, lies in the ability of the organisation to acquire and utilise knowledge and apply this to the development of new products (**T4**). Christensen (2013) also argues that firms need to keep **scanning** the environment for **new technologies** and possibilities to avoid getting overthrown by existing and new competitors. The scans can highlight new technologies and influence the idea generation process and the idea screening process. These technologies can be seen as threats, or possible sources for collaboration.

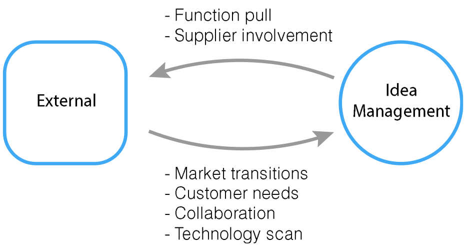


Figure 28 Linkages between the external environment and the idea management process

Figure 29 highlights the following examples of information and knowledge linkages between prior innovation and idea management. Christensen showed (3.1.2) that the customer's demand is not always in line with the organisation's technology development. Sometimes the market is just not ready yet (wrong timing). To avoid the killing of projects and loss of resources invested in them, ideas, technologies, and innovation projects need to be **frozen**, i.e. stored to be utilised in a later stage (**P15**). This allows for internal input in the idea generation process. Even if they would never be further developed, their **success & failures** could be utilised. Knowledge and insights through successes can create new challenges, and failures can create new insights that benefit the generation of new ideas (Berkhout et al., 2006) (Section 3.1.2) (**T5, P13**).

Technology builds on technology and this is how a better performing technology comes into creation. There is always a link to other technologies for the development of novel and improved technology. Technological progress would be the result of a discontinuity of technologies only to be replaced by newer ones that perform better or better meet the customer needs. Innovation projects are not projects on their own. Prior technologies and established need to be analysed and utilised to develop better technologies (Section 3.1.2 & 3.2.2) (**P18**).

New ideas, and the internal and external knowledge obtained through the process, might provide enough reasoning to **discontinue** other technologies (Section 3.1.2) and focus on the development of the new ideas to replace them.

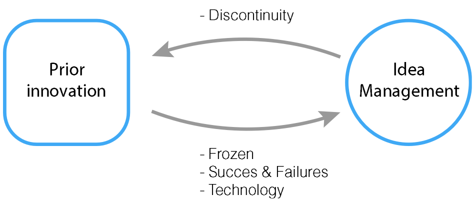


Figure 29 Linkages between prior innovations and the idea management process

Figure 30 highlights the following examples of linkages between portfolio management and idea management. Strategic goals should be translated into **challenges** to help steer idea generation (**P9**).

Barczak et al. (2009) argue that ideas that are more closely aligned to strategy are more likely to lead to a project that gets commercialized and is successful in the marketplace (Section 4.2). By incorporating innovation portfolio management, the innovation decision-makers can identify ideas that help reach a portfolio balance. These ideas can then be accelerated by **pulling** them straight in the development cycle (**T17, T19, P10**). Once new potential ideas are identified, the portfolio resource allocation can be adjusted to make resources available for the further development of potential ideas.

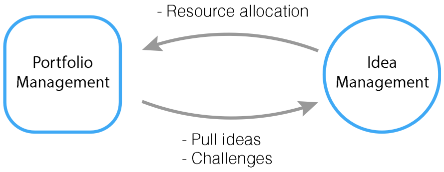


Figure 30 Linkages between the portfolio management process and the idea management process

Once ideas get selected they go through the **development** cycle, as shown in Figure 31 (further illustration in Section 5.3). However, if an idea got into the development cycle through **misguidance**, it can be returned to generate new ideas and help solve the challenge. This misguidance can happen when the customer wants/needs were misunderstood, or a supplier highlighting new risks in the development, or through market changes whereas a new patent does not allow the idea to be further developed but requires a new way to solve the challenge. In these cases, it would be a waste of resources if the project was killed and a new process would have to start.

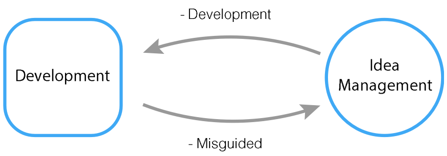


Figure 31 Linkages between the development process and idea management process

The idea management model is highlighted in Figure 32. This overall model shows that a new idea can be triggered through changes in the external environment, internal developments, or through market information obtained by launching and following other innovation projects, and a need highlighted by executives and provided top-down to balance the portfolio. Ideas create new concepts, successes create new challenges, and failures create new insights to be utilised in the development of new ideas.

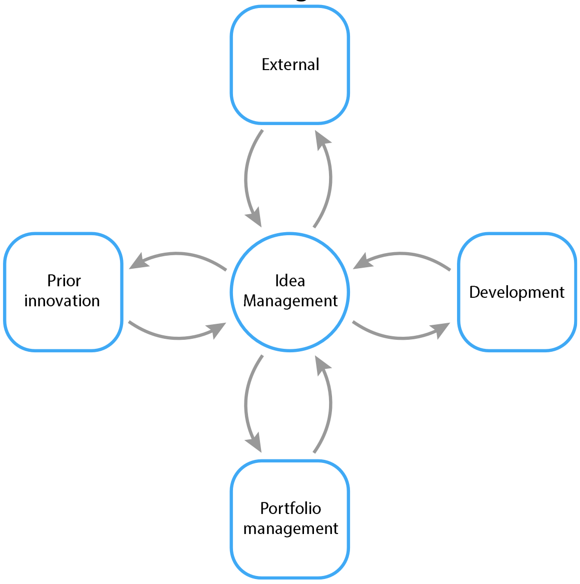


Figure 32 The idea management process and its interdependencies

5.3 Development cycle

Following the idea management process, this Section will illustrate the development process, and the "launch & follow" process (Figure 33). The section will start with the development process and ends with an elaboration on what the "launch & follow" process entails.

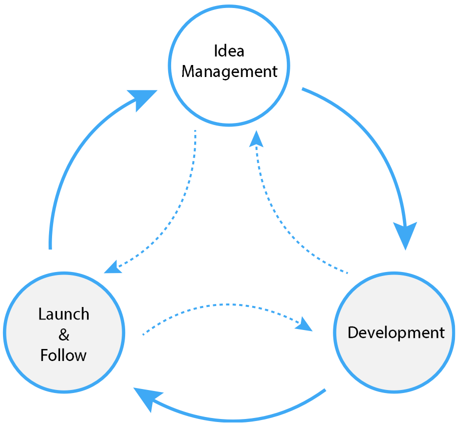


Figure 33 Development and launch & follow

Once an idea is selected, a series of resource intensive activities would start surrounding its development. These include gathering information, communicating with key players, building requirements, testing, and evaluating the product.

To better understand the development activity, the process is zoomed in and illustrated in Figure 34. The process resembles a cycle, in which feedback loops and iterations can occur. The model builds upon the "Build-test-feedback-revise" model (Section 3.2.2) (Appendix E: Stage-Gate development).

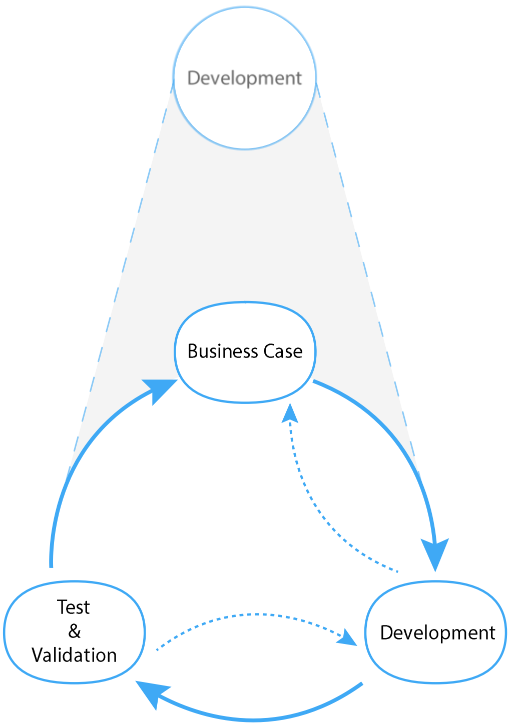


Figure 34 Development cycle adapted from (Cooper, 2014b)

Build business case	Study user needs & wants, pain-points, requirements
	Gauge interest, purchase intent, preference based on virtual concept and sales materials
Development	Early test of product in development
	Gauge customer reaction & purchase intent based on prototype
Test & Validation	True prototype tests in actual conditions
	Gather feedback from the customer or user
	Revise the value proposition, benefits sought and the product's design based on the feedback and start the loop again.

Table 16 Development activities

The cycle can differ per organisation, and activities can be skipped. The general activities are as followed (Table 16). **(1)** The review starts of by scoping for preliminary market and technology information at low cost and in a short time. For the market assessment, this could involve a library search, contacting key users and focus groups to determine the market -size, -potential and -acceptance. For the technical assessment, this can be a quick in-house appraisal of the proposed product to assess the development and manufacturing feasibility, and possible costs and times to execute. A business case is built with a technical and economic feasibility analysis focussing on customer needs and project costs. **(2)** The product is developed and detailed test, marketing and operations plans are made. **(3)** The project's viability is tested. This includes the product, the production process, customer acceptance, and the economics of the project. The application is evaluated and validated (**T7**).

In the case some errors came to light during the development activity of the technical or market assessments (e.g. the wrong industry was identified as a potential candidate). The process would return to the business case activity. If the technology works, but the wrong industry was chosen, the development activity can then be skipped and the product can be tested in the right industry. In the case it became clear that the product did not function as was intended to, or the customer's need were not addressed, during the test and validation activity, the activity returns into the development activity and tries to adjust and improve the design.

After each loop, the project moves closer to the final product design. The development cycle would continue until a satisfying result is achieved (i.e. the product comes close enough to solving the identified problem, or the customer needs are sufficiently addressed). At any point in the cycle, the decision can be made that the product is ready for launch, or that the project should be terminated.

The development process also possesses many linkages to other processes, like the idea management process (Figure 32).

Figure 35 shows several linkages of the development process with the external environment. The Figure highlights the involvement of **lead-users** to obtain feedback during the development process. Von Hippel (1988) proposed to incorporate lead-users in the concept generation, development, testing, and pre-market forecasting to identify important modifications and improvements (Section 3.1.2). This also helps innovation decision-makers to focus more on the customer needs rather than on the decision-points (gates) (**P10**) (Section 3.2.2). By providing lead-users with prototypes, the user can provide feedback. In the case of a functional **prototype** (i.e. toolkits), the customer can assist in the development of the product and highlight some important changes. The prototype, concept or an early beta version (toolkit, Section 3.1.2), can be put in front of a customer early to further improve the product. Customers often don't know what they need or want in the first place, following the words of Steve Jobs: "People don't know what they want until you show it to them" (Isaacson, 2011). Therefore, it is impossible to get a 100 percent accurate product definition before the development phase. Requirements simply change in the time between the beginning and end of the development phase. This could happen because a new competitive product was introduced or a new technological possibility emerged or simply because a new customer need showed up. The product's design adapts to new information and changing conditions.

The Figure (Figure 35) also highlights that the organisation can **provide knowledge and skills** to external stakeholders to further develop a complementing technology (e.g. a car manufacturer providing knowledge and skills to external engine manufacturers). The other way around is also important to highlight, whereas the external environment is scanned for technologies and capabilities that can be bought or outsourced.

The development process can also happen through a joint-venture alliance or other forms of **collaboration** (see Section 3.4.3), whereas organisations and individuals share their technologies and insights and together develop a new product (e.g. to solve the climate change).

During the development process, the organisation can also choose to **inform the supplier** of the development (Section 3.4.3). This would provide the supplier enough time to make sure that all the needed materials are ready in time. Also, **established relationships** can be **informed**. E.g. these organisations would then receive enough time to develop complementary goods, so they can be ready in time for the product's launch.

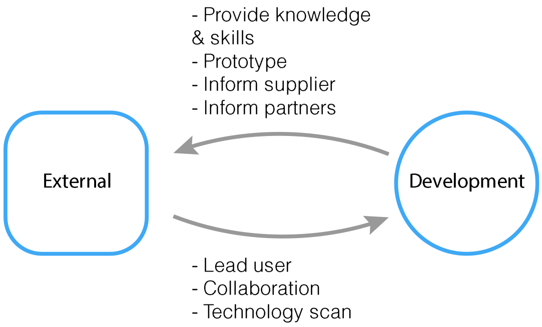


Figure 35 Linkages between the external environment and the development process

As is illustrated in Figure 36, the development process provides information to the innovation portfolio management process so that the portfolio can be reviewed **(P14)**. The information allows for portfolio analyses of the innovation projects, so that a portfolio balance can be achieved **(T11)**. During the portfolio review, it can become clear that the project either has a high potential (i.e. financial benefit or customer satisfaction), or low potential (i.e. high risk with a low return). In this case, the process can adjust the resource allocation of the project, which affects the development process. In the case that the project is not strategically aligned, or damages the portfolio balance, the decision can be made to terminate the project and frozen. When innovation projects are terminated during the development process (e.g. due to the negative portfolio impact, resources must be allocated elsewhere), they must be stored so that they can reach their highest potential value. This could be done through licensing, or continuing the development when the market (i.e. customers, infrastructure) is ready for it, or utilising the knowledge obtained for other technology developments that are closely related.

Cooper et al. argued that organisations often develop multiple projects in closely related markets. These innovations often show synergy or incompatibilities and might complement or substitute each other, which could reduce the resource spending on these projects. Therefore, the identification of these **interactions** and linkages between the innovation projects should be facilitated through visual methods or systems that can identify these methods **(T10)**.

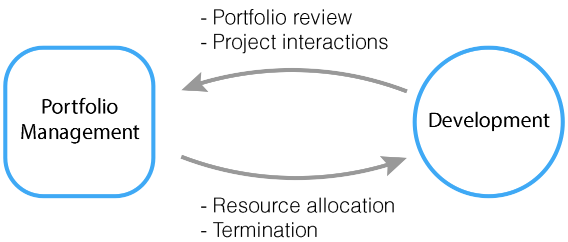


Figure 36 Linkages between the portfolio management process and the development process

Figure 37 shows some examples of how the development process is linked to the "launch & follow" process. Once the development cycle produces a satisfying result, the final design is created and the product can be manufactured and brought to the market. In some situations, the launch of the product reveals some issues for which the design must make some incremental changes or improvements. Some examples of this are i.e. car manufacturers taking back cars to fix an issue in the design. Or software improvements, such as bug fixes or minor additions.

After a product is launched and followed throughout its existence, it can expose a new market/niche. In this case, the product was used for a different purpose than it was intended for. This could allow for a feedback loop to change the design incrementally, so that it better fits the need of this group/niche.

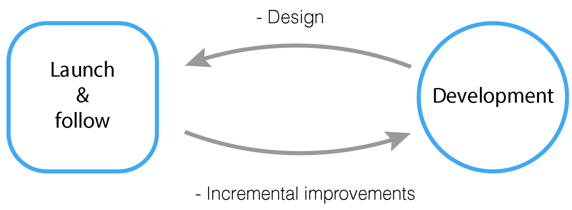


Figure 37 Linkages between the launch & follow process and the development process

Other linkages that have not been illustrated are also present. The linkages to the idea management were already discussed in Section 5.2. The linkages to prior innovations allow for the development processes to utilise knowledge of previous successes, failures, technologies, and established relationships. This helps the process to further build on this knowledge and identify opportunities, pitfalls, and lead-users to incorporate in the process.

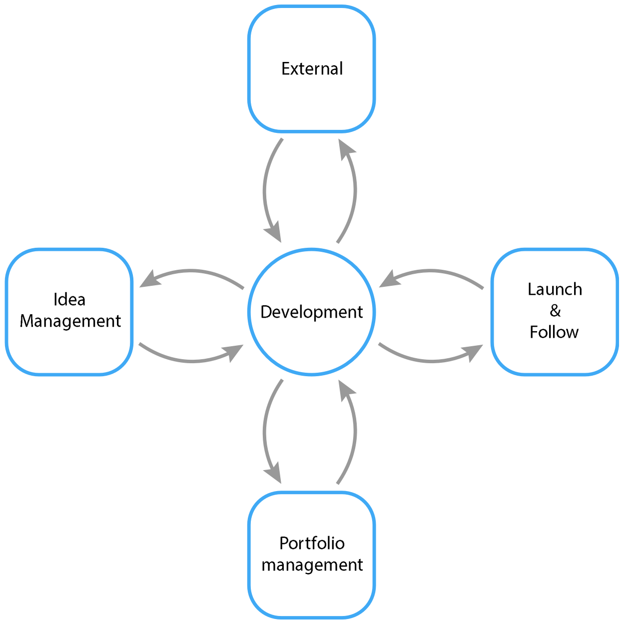


Figure 38 The development process and its interdependencies

5.3.1 Launch & Follow

The next activity is the "launch & follow" (Figure 39). This activity revolves around the manufacturing, marketing, implementing, a new (or improved) product, and following its successes and failures, impact, utilised technologies and relationships, to store this knowledge for future developments.

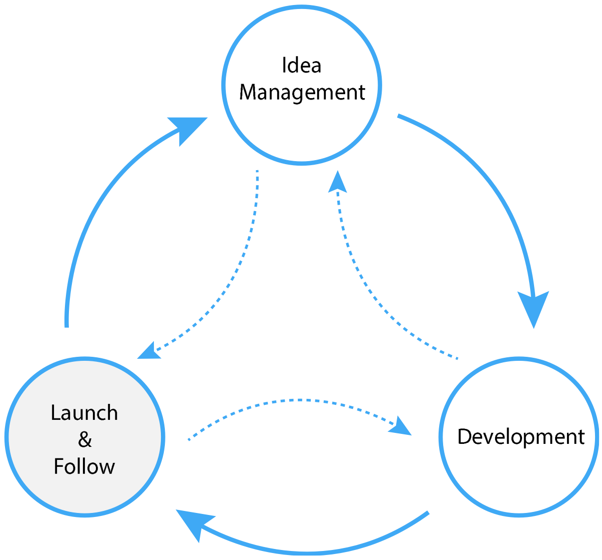


Figure 39 Launch & Follow

Sections 5.2 & 5.3 have highlighted several information and knowledge linkages to current and prior innovations, technologies, and established relationships. These linkages can only be made possible, if this knowledge is stored and linked to the development of new products. Section 3.4.4, highlighted that decision support systems with knowledge management capabilities can perform this process. Section 5.6 will discuss elaborate on this in more detail.

The application domain and theoretical domain, have highlighted several important implications for the activity of "launch & follow". Von Hippel (1988) proposed to incorporate lead-users in the post-launch as opinion leaders, to identify important modifications and improvements for the next developments (Section 3.1.2). Cooper et al. (2001b) highlighted that after the product is launched it is to be followed and analysed for its performance. A post-audit to identify the project's successes and failures, and knowledge obtained internally or externally that can be used to refine the product development process and make better planning in the future **(T9)**. Developed technologies must be codified, stored and mapped, so that they can be easily identified, accessed and utilised in future innovations **(P19)**.

Hanna et al. (1995) argue that business-product companies often keep trying to find new uses or markets for their products (Section 3.1.2). Therefore, the process needs to be followed and managed, even after the product's launch. At some point, the new product project must be terminated to make room for a new product development.

During the Launch & follow activity, the innovation portfolio management can influence the process. This can be done adjusting the resource allocation to the activity, e.g. by terminating the project (e.g. if it brings damage to the firm or its risks don't overweigh the benefits).

5.4 Innovation Portfolio Management

The innovation portfolio management process involves the management of the innovation portfolio, using innovation portfolio methods, so that a portfolio balance can be achieved, i.e. achieving all four major portfolio goals (Section 3.3.4). Section 5.1 developed an innovation portfolio management model, that still needs more iterations and more lead-user involvement. The iterations would highlight changes and improvements and bring the model closer towards a design that can be generalised and serve most innovating organisations. The model exists of several innovation portfolio methods (see Section 5.1) and assists organisations to analyse their innovation portfolio. Innovation decision-makers can utilise the visuals, numbers, and reports on the portfolio's balance (**P14**). Key performance indicators can be analysed, such as the strategic alignment or financial benefits of innovation projects, to help decide whether the projects should be terminated, continued, or a change in the resource spending should be made. The model, however, does not show when and how the process should be performed, and what the linkages are between the innovation portfolio management process and the innovation process. This Section will help to elaborate more on these aspects of the innovation portfolio management process.

Sections 5.2 & 5.3 illustrated that the innovation portfolio management process is present throughout the innovation process (see e.g. Figure 32 & Figure 38). The decisions the process brings, outweighs the decisions made on the innovation project (Section 3.3) (**T11**). To help illustrate why, the following example is given. If an idea or concept delivers great financial benefits, the innovation decision-maker will probably decide to further develop the project and invest resources in it. However, once it becomes clear, during an innovation portfolio review, that the project damages the innovation portfolio's balance (i.e. is not aligned to the strategy) the decision-maker would probably decide to put the project on hold or terminate it. Portfolio decisions are made from a more (long-term) strategic perspective and need to outweigh the innovation project decisions.

An important aspect of the innovation portfolio management process, is the ability to analyse if innovation projects are aligned with the organisation's strategy. To perform this analysis, the innovation portfolio management process needs the strategy to be pre-defined and revised if needed, so that it knows what "good" projects should look like (**T18, P8**) (Alemán et al., 2015) (Section 3.3.3). Therefore, the organisation's strategy needs to serve as the core for the innovation portfolio management process and needs to be incorporated in the innovation support framework as such. Following this proposition, the innovation model highlighted in Figure 27, is complemented with the innovation portfolio management process and the strategy as the core of the process, as can be seen in Figure 40. The model illustrates that innovation portfolio management is present throughout the innovation process and helps to link the innovation process with the organisation's strategy. The arrows in the model, highlight the influence and presence of the process. They show that there is a 2-sided influence on and from the innovation portfolio management process, as was illustrated in Sections 5.2 5.3 and 5.3.

Section 3.3 (mostly Section 3.3.3) showed that the innovation portfolio management process is operationalised through the performance of innovation portfolio reviews. The portfolio reviews analyse the entire set of development projects, examining the mix, balance, and prioritization of projects. Alemán et al. argued that innovation portfolio reviews should be frequently performed, i.e. monthly-semi-annually depending on the context of the organisation (e.g. number and length of innovation projects). The authors proposed to introduce two levels of portfolio reviews (**T10**).

(1) A high-level strategic review that is performed semi-annually, where innovation decision-makers meet and decide upon the innovation portfolio. This review focusses on redirecting the innovation resources to maintain a strategic alignment. Innovation projects are ranked, based on predefined criteria by the organisation (see Sections 3.3.3 and 5.1.1). The decision-makers identify the available budget for innovation and decide which projects to fund.

(2) The second type of portfolio review, involves the optimization of the current innovation portfolio, and is performed more frequent (i.e. on a monthly basis) (Section 3.3.3). This process focuses on freezing or terminating innovation projects to achieve portfolio balance. Examples are the termination of Innovation projects because they are not aligned to the strategy, or the portfolio exists of too many risky long-term innovation projects.

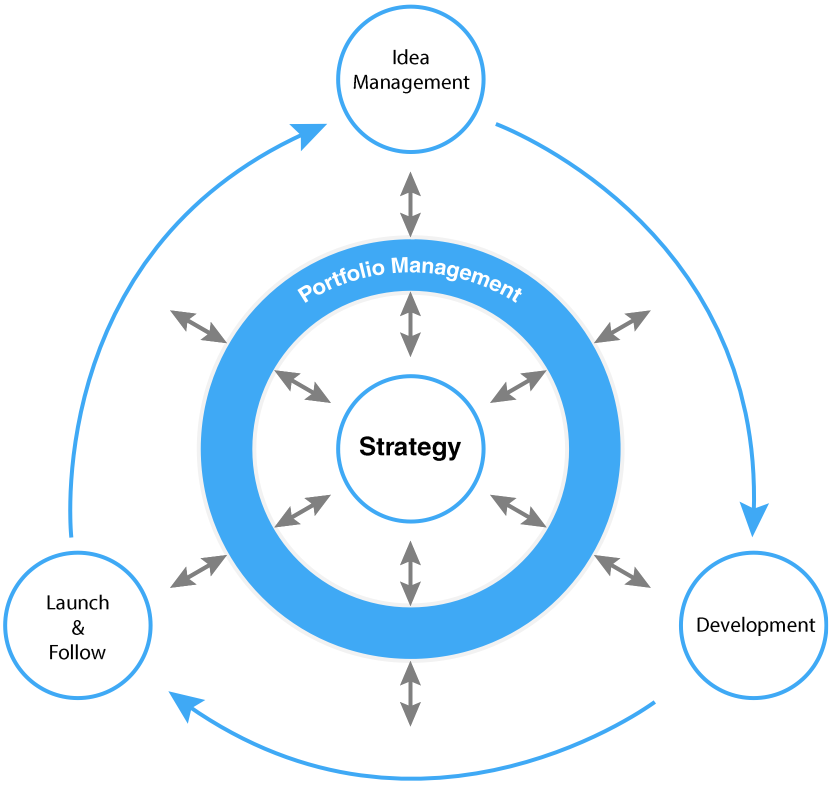


Figure 40 The Innovation portfolio management process parallel to the innovation process

As was illustrated in Section 5.2, innovation portfolio management is not solely focussed on killing or accelerating existing developments, but also helps to steer the idea generation process, and accelerate new ideas into development to balance the portfolio. Therefore, the innovation portfolio reviews serve three main purposes, which are highlighted in Figure 41.

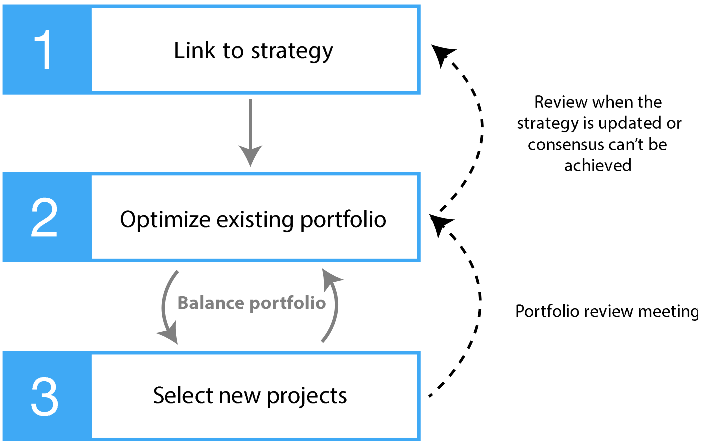


Figure 41 The main activities of the innovation portfolio management process as adopted from Alemán et al., 2015

Figure 41 illustrates the main three activities in portfolio reviews (Section 3.3.3), identified by Alemán et al. (2015) (**T19**).The Figure shows that the strategy needs to be frequently revised. Changes in the external environment (e.g. market transitions, technological research, or legislation) might require the strategy to be adapted. A target portfolio structure provides a strong basis for decision-making and creates a common expectation and understanding about what should be achieved in the portfolio reviews (Section 3.3.3).

5.5 INNOVATION SUPPORT FRAMEWORK

Section 3.1.2 highlighted that Innovation is the continuous accumulation of knowledge, and to succeed in the process, an organisation should possess the ability to acquire and utilize knowledge. Knowledge is a competitive weapon in the innovation process, and firms often acquire knowledge by means of strategic alliances with external parties. Sections 5.2 and 5.3 further illustrated the existence of information and knowledge linkages to the external environment. The Stage-Gate process, discussed in Section 3.2.2, fails to highlight the information and knowledge exchanges that occur during the innovation process. Seeing that most firms acquire knowledge, information and skills from the external environment for their innovation process (Barczak et al., 2009; Berkhout et al., 2006; Chesbrough & Bogers, 2014), these linkages need to be addressed in the management of innovation projects. The model remains linear and sequential, and fails to highlight the many feedback loops and iterations that come to pass in the real world. The Cyclic Innovation model (CIM, Section 3.1.2) addresses the information and knowledge linkages and illustrates how these exchanges occur in an open innovation arena. However, the CIM model does not illustrate the activities that need to be performed to obtain the required knowledge. The model shows the innovation process to be continuous and does not split the process in stages, resulting in the decision-makers not knowing what information is needed at which stage. Decision points are not highlighted in the process, which could result in the late identification of failing innovation projects (i.e. cost outweighing the overall benefit). Thus, the model, does not give the project management benefits the Stage-Gate process provides (Section 3.1.2).

However, the CIM model does illustrate the type of information and knowledge exchanges that occur within the innovation process and the identification of stakeholders. Therefore, this research project attempts to develop an innovation support framework that incorporates the strengths of both models into one framework. The model builds on the previous Sections (5.2, 5.3, and 5.4), and incorporates linkages to the external environment, as is illustrated in Figure 42 in the form of grey arrows. The final model includes the four innovation management practices that were recognized by Tidd & Aleman (2016) to be significantly associated with superior innovation performance (see Sections 3.2.2 and 3.4.5).

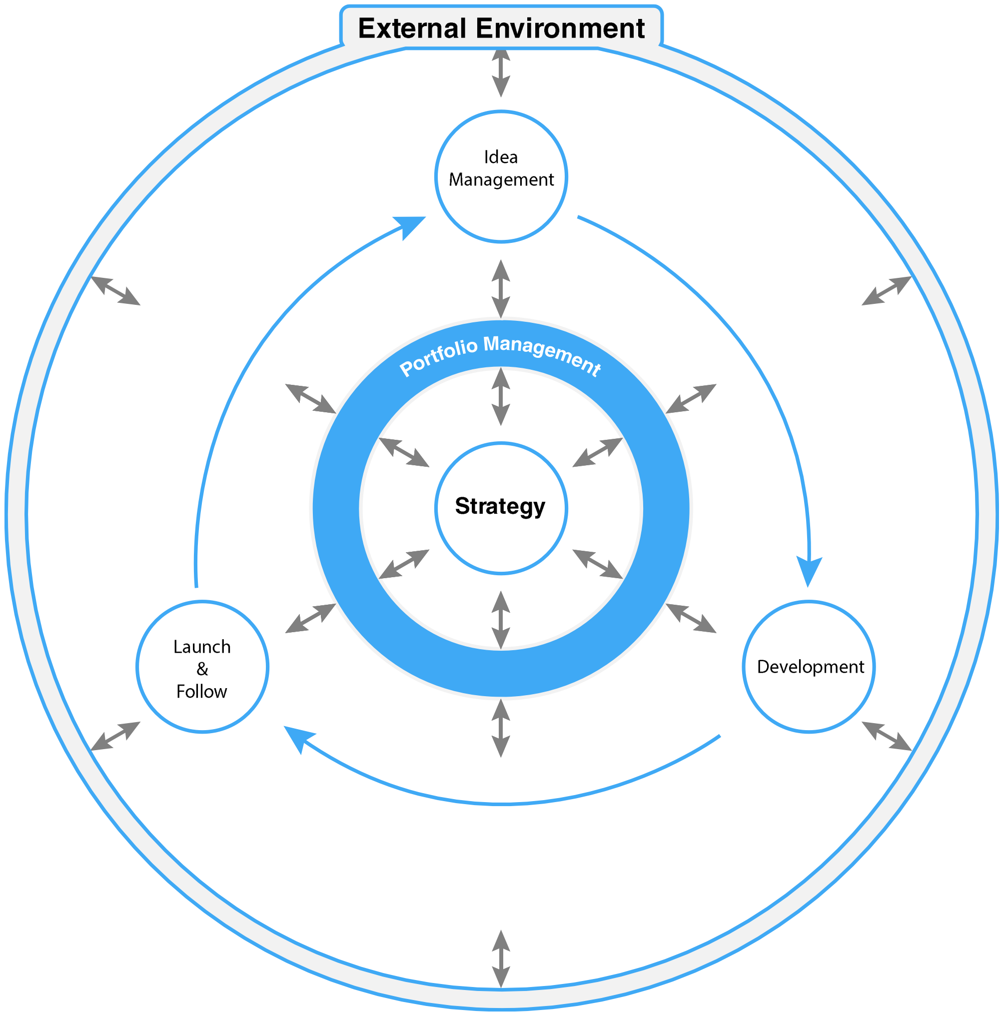


Figure 42 The Innovation Support Framework illustrating the linkages between the innovation process, innovation portfolio management process, and the external environment.

The model builds on the fact that innovation is continuous, but splits the process into several activities, so that the process can be managed to some extent **(P17)**. It illustrates that previous innovations allow for the creation of new innovations to improve and replace them, and new innovations disrupt the market resulting in the discontinuity of old innovations **(T3)**. Knowledge is shared internally and externally, leading to more novel and creative developments **(T1)**. The model also shows that stages (and activities) can be skipped, or returned to. The innovation can start anywhere in the model, and finish anywhere, once a satisfying result is achieved. All the knowledge and information is stored, and innovation projects are followed even after their launch so that their successes and failures can be taken into consideration in new development projects.

Section 3.3.1 highlighted the need for a management method to help manage the external linkages, and link the process with the innovation portfolio management and innovation management process. The method needs to identify, store, access, and utilise relationships with external innovation stakeholders. Chesbrough and Brunswicker (2013) argue that 78% of the organisations that develop new products, also practice open innovation (Section 3.4.3). The knowledge and information networks with the external parties are highly valuable and require maintenance as well **(T8)**. Following the model illustrated in Figure 42, this process must be present throughout the innovation process **(T12)**.

Section 3.4.4 & 3.4.5, highlighted the issue of absorptive capacity. To fully utilise external information, the organisation must possess the knowledge to process and utilise this information. Internal research enhances the organisation's ability to use utilise external knowledge and technology. Rosenberg & Steinmueller (1988) highlight that organisations that fail to exploit external technology and knowledge may be at a severe competitive disadvantage.

5.6 DECISION SUPPORT SYSTEMS

The innovation support framework illustrated in Section 5.5, shows that external linkages (outer grey arrows) to sources of data, information, knowledge and skills are present throughout the innovation process. These linkages were elaborated upon in Sections 5.2, 5.3, and 5.4, including the internal linkages to prior knowledge within the organisation. However, the ability to conduct business and enhance the competitiveness of firms is something that is not entirely dependent on the organisation. Therefore, it is important to have means to facilitate fast access to internal and external sources, and become a potential investment for others in the development of new technologies and services (Section 3.4.3). This Section will discuss the usage of intelligent Decision support systems (see Section 3.4.5 and 3.4.6) to assist the decision-makers in utilising the internal and external knowledge linkages within the innovation management process.

Section 3.4.4 highlighted the role of (Group) Decision support systems as facilitators for innovation decision-making. These tools complement the decision-making process surrounding innovation in several ways. The Section illustrated that the tools would bring fast and remote communication, stakeholder analysis, information and knowledge-identification, -gathering, and -storing through knowledge management, and the ability for users to customize models to their needs, see Table 5 (**T20, T22**). The Decision support systems, provide innovation decision-makers fast access to external information. This way, participants of the decision-making process can instantly provide their feedback, insights, information even if they are not geographically close. This information is then stored, so that others can use it, or it can be accessed in a later stage. To help store, and access knowledge, Decision support systems utilise Knowledge management (3.4.4). Knowledge management helps to store, access, and disperse knowledge throughout the organisation (**T23, P7**).

Section 3.4.3, illustrated that most organisations innovate together with other parties (open innovation) to establish new partnerships, explore new technological trends and identify new business opportunities. Business Intelligence can support and accelerate these activities (Section 3.4.5). Section 3.4.5 illustrated the complementing role Business Intelligence has in Decision support systems. This methodology allows for fast (sometimes real-time) interactive access to external (and internal) data, which provides many benefits to the innovation management process (e.g. real-time access to external data). It can help decision-makers make informed decisions and reduce the resource intensity (i.e. time and effort) needed to do so (**P20**), by providing real-time access to market information and giving realistic and true numbers (e.g. on market transitions and market sizes).

Business Intelligence allows the decision support system to utilise external technologies and position the new developments in the context of their application environment (**T21**). This would accelerate the feedback loops and enhance the development. Section 5.3 illustrated the role of prototyping and proving toolkits (see Section 3.1.2) to receive feedback and insights on the development. Technologies, such as Virtual Reality, 3D modelling, and software betas, could allow for fast feedback iterations and accelerate the Development cycle (Section 5.3).

Section 3.1.2 proposed to utilise the Cyclic Innovation Model (CIM) model as a strategic communication tool (Berkhout, 2000), to assist innovation decision-makers to maintain established relationships, establish new partnerships, or share the risks involved in the innovation process (e.g. through outsourcing or co-development). The model would help to indicate the need for specific partnerships, by defining the preliminary building blocks needed for the innovation. These building blocks highlight the **(1)** the disciplines needed in the to be able to develop the specific technology, **(2)** the technologies needed to develop the specific product, **(3)** the products needed to deliver the specific service. Berkhout et al. (2010) argued that the model would improve the communication between many diverse players, because each player would be able to identify his position in the arena as well as his relationship with the other players (Section 3.1.2). This allows the players to identify and address all the relevant information streams with the other players, and recognize knowledge gaps.

With the help of the CIM model, missing information and knowledge building blocks can be highlighted, and needed partnerships can be identified and established with new, old, or current relationships. Intelligent decision support systems can assist this approach, by gathering information and data on the required knowledge, information, skills, and technologies and highlighting the parties as potential sources of collaboration. Some examples of external databases, where organisations publish their services, are Innoget ("Innoget," 2017) and Innocentive ("Innocentive," 2017). These marketplaces exist of organisations and individuals from the business environment and academic communities. Disciplines, technologies, products, information and knowledge are sold and exchanged in these platforms. Utilising these linkages can introduce new innovation partners that collaborate in the development and help to share the risks involved in the innovation process (**P17**).

Section 3.4.3 also illustrated how external sources of financial aid can benefit innovation projects. The example of how Shell (Section 3.4.3 , "the case of Shell"), reduces the risks involved by the constant search for subsidies and grants that provide the projects with financial benefits. Integrating these external opportunities for financial aids can help reduce the risks involved in innovation projects and serve as an incentive for organisations to develop more long-term innovations.

These external sources (databases) of collaboration or financial aid, can be made visual within the innovation portfolio management process. They can be labelled as external opportunities to reduce the risks involved in the innovation process and help to reduce the technical, market, and financial risks involved in innovation projects. Business Intelligence can help gather this data and make them visual in Decision support systems, so innovation decision-makers can utilise them.

Section 5.3 argued that synergies or incompatibilities between innovation projects need to be identified and made visual for innovation decision-makers (Section 3.3.1). These developments can complement or substitute each other, and therefore could reduce the resource spending on the projects (and thus help reduce their financial risks). Using Decision support systems, together with Knowledge management and portfolio methods (such as technology roadmaps, Section 3.3.3), these linkages can be identified and made visual to assist the innovation decision-makers in their decisions regarding the adjustment of the resource allocation of these projects or even terminating them (**T9**).

Together with Business Intelligence and Knowledge management, Decision support systems allow for real-time remote collaboration between innovation stakeholders, utilising internally stored knowledge and information, and lets them participate simultaneously in the innovation decision-making process. The systems help to accelerate the innovation process by facilitating the data, information, and knowledge exchanges within and outside of the organisation.

5.7 CONCLUSION

The Chapter builds upon the insights from Chapters three and four together with several best practices studies to develop an innovation portfolio management (IPM) tool and design an innovation support framework to help position the IPM process in current innovation management practices.

> *SRQ4: What are the relevant criteria for an innovation portfolio management tool, that can serve as a basis for future co-development with lead-users in the application domain?*

The Chapter starts by introducing five portfolio methods that are incorporated in the concept design of the IPM tool. The portfolio methods follow previously identified design requirements from Chapter 3 and 4, and are as followed. **(1)** A score-card that serves as the basis of the tool. This method allows for organisations to fill in the relevant data and information regarding the innovation, and rank projects based on predefined criteria. **(2)** The scoring method is complemented with a NPV indication, which helps decision-makers to think about future ways of income. **(3)** The scoring method, together with the NPV method, is also complemented with the Bang-for-Buck index. The index helps organisations to take budget restrictions into account when ranking and selecting innovation projects. **(3)** To help visualise the portfolio balance, the IPM tool incorporates **(4)** bubble diagrams and **(5)** strategic buckets. The Section ends by emphasising that the IPM tool model requires more iterations in its development, to help progress the model towards one that can be applicable to most innovation organisations.

> *SRQ5: What are the relevant criteria for an innovation support framework, that can adapt to the user's context and methodology and help position and integrate the innovation portfolio management model in current innovation management practices?*

The chapter continues by introducing the building blocks of the innovation support framework. The innovation process is split into three key activities, that are illustrated in a circular and continuous manner (Figure 27). The activities exist of: **(1)** the idea management process, **(2)** the development cyclic process, **(3)** and the Launch & Follow process. First, the idea management process is illustrated. This process is split up to illustrate the linkages between the several processes that influence the idea management process and gives examples of these linkages, based on theory. The Figures in Section 5.2 show that the idea management process influences and is influences by the external environment, prior innovation knowledge, the innovation portfolio management process, and the development process (cycle). The Section ends with an overall Figure of the Idea management process (Figure 32), including the linkages the Section discussed.

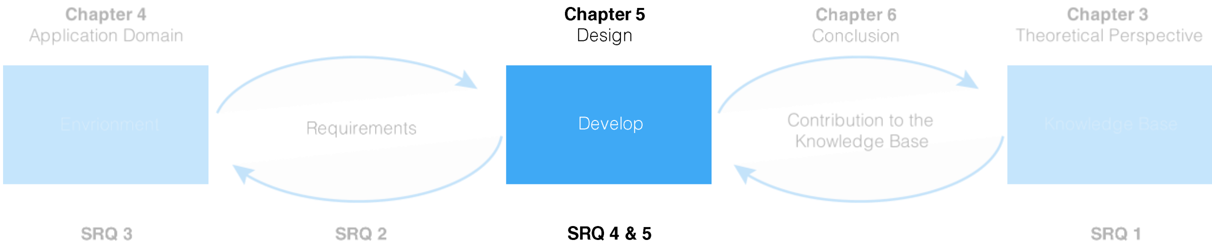
The second building block introduced, is the development cycle (Section 5.3, Figure 34). The cycle builds on the build-test-feedback-revise process from Cooper (Cooper, 2014b) (Section 3.2.2 and Appendix E: Stage-Gate development). The process is adapted by portraying it in a cyclic and continuous manner. Feedback loops were introduced and additional linkages to the external environment. The cycle exists of three main activities: (1) creation of a business case, (2) development of the product, (3) test, evaluation and feedback for validation. The Section illustrates that the activities can be skipped, or returned to if needed. The cycle and its activities, would continue until a satisfying result is achieved. The many linkages of other processes (i.e. idea management, portfolio management, launch & follow, and the external environment) to the development process are separately illustrated, and the Section ends with an overall Figure of the development process (Figure 38), including the linkages the Section discussed. The final building block of the innovation process, the "Launch&Follow" process, is discussed in Section 5.3.1. The process helps to illustrate why knowledge, obtained and created during the innovation process (including post-launch of an innovation), must be stored so that it can be utilised in future developments.

The chapter continues by introducing two new building blocks to the innovation support framework: **(1)** the strategy, **(2)** the innovation portfolio management process. The framework (Figure 40) illustrates that innovation portfolio management (IPM) is the link between the strategy and the innovation process. The framework shows that the IPM process is present throughout he innovation process, and can influence the process at any point. The Section ends with some examples of how the IPM process can be performed in practice, based on best practices (Section 5.4).
The last addition (building block) to the support framework, is the influence the external environment brings. The final innovation support framework (Figure 42) incorporates the external environment and illustrates that external parties, data, information and knowledge, can influence the innovation and innovation portfolio management process. The framework also illustrates that the innovation process and innovation portfolio management process can influence the external environment.

The innovation support framework (Figure 42) incorporates phases including their key activities, and tries to introduce project management benefits by doing so. The framework differentiates itself from the gating-approach (Section 3.2.1), by illustrating the innovation process as a continuous process, and introducing feedback loops. The framework also attempts to illustrate the many information and knowledge linkages throughout the innovation process. The framework, however, must be complemented with the CIM model to help illustrate the diverse innovation stakeholders in the innovation arena. The CIM model can be utilised on project basis, to help recognize gaps of knowledge, technology or products, and help identify the role the stakeholders play and their relationship with the other stakeholders. This knowledge can be stored to help utilise established partnerships in future developments, and accelerate the innovation process.

The last Section of Chapter 5 introduces potential solutions to support the innovation process and innovation management processes, by proposing the use of intelligent decision support systems. The systems assist the decision-maker, by gathering relevant data, information and knowledge, and presenting it to the decision-maker in such a fashion, that he/she can utilise these sources to their maximum potential. The systems allow for fast (instant) information and knowledge exchanges, and thus capabilities such as: real-time collaboration internally and externally for remotely located stakeholders, real-time information on market transitions, and internal linkages between innovation projects (e.g. similarities between technologies). The systems allow for the integration of external databases (Section 5.6). This integration could complement for example the CIM model, by identifying potential partnerships. As well as identifying possible financial aid in the form of subsidies or grants. Incorporating these information sources, can help reduce the risks associated with innovation projects.

Sub-research questions 4 and 5 have been answered. Following Hevner's guidelines (Section 2.2), Design Science research can contribute in three ways. **(1)** The design artifact (SRQ 4 and SRQ5, Chapter 5), **(2)** the foundations (SRQ 1, Chapter 3), **(3)** the methodologies, SRQ 2 and SRQ 3, Chapter 4). The last step in Design Science research involves the communication of the contributions to researchers and other relevant audiences (Section 2.3), which is done through Chapter 6: Conclusions.



6 CONCLUSIONS

The last Chapter presents the conclusions and summarizes the significant findings of the study. It is structured as follows. It starts by elaborating how the research questions were addressed and the objectives could be obtained. Followed by the research limitations and the contributions made along the research, and ultimately providing recommendations for further research.

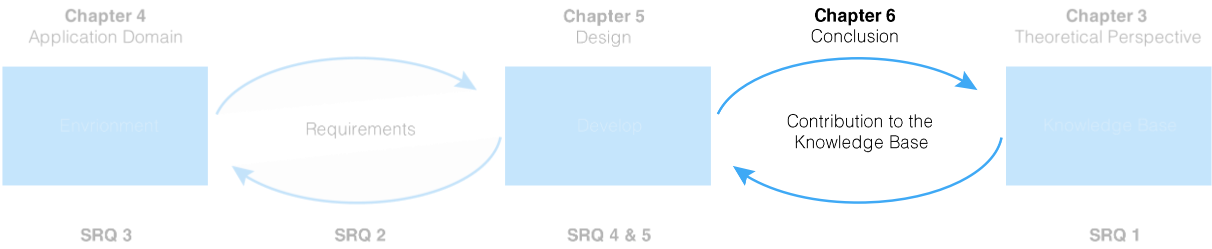


Figure 43 Research structure Conclusions

The Chapter builds upon all the other elements of this research (Figure 43) and proposes its contribution to the knowledge base in the form of two artifacts, i.e. a concept innovation portfolio management model and innovation support framework to assist innovation decision-makers in practicing innovation portfolio management in their organisation's context.

6.1 RESEARCH QUESTIONS AND OBJECTIVES

To make clear how innovation portfolio management relates to other innovation practices, and help the user to identify how and when the process needs to be performed within the innovation process. A research objective was defined as follows:

RO ***to give recommendations to the improvement of innovation portfolio management (IPM) practices, by identifying requirements, and designing an innovation support framework that can assist practitioners in positioning IPM in their innovation process.***

To gain a better understanding of how the innovation portfolio management process can meet the requirements and needs of the application domain, a model is co-developed with lead-users during the research project. The model takes on the form of an IPM tool, so that it can be iteratively improved. A sub-research objective was defined as follows:

SRO ***design an innovation portfolio management model, that takes the form of a IPM tool and serves as a basis for further development together with lead-users in the application domain.***

To provide guidance for reaching the objectives a main research questions was formulated as:

RQ **What are the four most important criteria for an innovation portfolio management model, that can adapt to the user's internal and external environment and integrate with the user's current innovation practices?**

The main question was segregated into five sub-questions:

SRQ1: Which theories are linked to an Innovation Portfolio Management decision support system, capable of adapting to the user's context and integrating with the user's current innovation practices?

The theoretical domain showed that innovation is a continuous process and builds upon prior innovation (Section 3.1.2). Several models were identified to help manage the innovation process. The CIM model (Section 3.1.2) helps to illustrate the many information and knowledge linkages throughout the innovation process, and identify the many diverse innovation stakeholders including their role in the innovation process and their relationship with other stakeholders. The gating-approach helps to illustrate the project management benefits the Stage-Gate model possesses (Section 3.2.2). While the innovation portfolio management process showed that, by also continuously linking the innovation process with the organisation's strategy, better results can be achieved (when compared to the other models) (Section 3.3). The strategic decision-making involved in the innovation process, shows that innovation decisions are often made with a lack of information and are often affected by influences from the external environment (Section 3.4). Decision support systems, complemented by Business intelligence and Knowledge management capabilities, are recognized to help reduce the uncertainties the innovation decision-making process entails, improve the ability to acquire and utilise information and knowledge internal and external to the organisation, and reduce the complexity and resource intensity of the process as a result (Section 3.4.4 & 3.4.5).

SRQ2: What are the requirements for an Innovation Portfolio Management model capable of adapting to the user's innovation context and innovation practices?

Innovation portfolio management models should include two to- four strategic portfolio methods and avoid financial portfolio methods. The innovation process needs to be present parallel to the innovation portfolio management (IPM) model and allow the IPM process to help steer the idea generation and idea screening of innovations. The innovation process should incorporate a cyclic development process that can iteratively co-develop innovations with the external environment. IT solutions help store and disperse knowledge throughout the organisation, and integrate with external sources of knowledge to help reduce the risks of innovation projects. These decision support systems (IT solutions) allow for customization to better integrate with the user's innovation practices, and real-time information and knowledge gathering to help the innovation process adapt to the internal and external innovation context. Chapters three and four generated a list of requirements, which can be found in Sections 3.5 and 4.4.

SRQ3: To what extent do the currently employed solutions at the commissioning organisations, meet the identified requirements?

The innovation portfolio management tool developed by B&C (Section 4.1) lacks the ability to adapt to the user's context, and neglects external knowledge sources or external stakeholders. It fails to provide the user the ability to customize the innovation management process, and therefore required too much effort and time to utilise (resource intensity). The tool possessed several financial portfolio methods that allowed for inaccurate analysis. However, the tool utilised mainly strategic portfolio methods, and helped the users identify their portfolio balance (Section 3.3.3). These strategic methods were perceived positively by the users and follow several design requirements identified.

The second solution, the EasyCrit innovation management tool developed by Critflow (Section 4.2) illustrates innovation management practices and innovation portfolio management practices as activities that follow each other, however these processes are present parallel to each other. The solution also neglects linkages to external knowledge sources and other innovation projects. However, the solution utilises several portfolio management activities, such as the upfront-definition of the organisation's strategy and linkage of the strategy to the idea generation process aligned with several requirements. It involves the whole organisation in the idea generation and idea screening process, and stores ideas and project that don't get further developed so that they can be utilised in future developments.

SRQ4: What are the relevant criteria for an innovation portfolio management tool, that can serve as a basis for future co-development with lead-users in the application domain?

The first concept innovation portfolio management tool (Section 5.1) consists out of five portfolio methods. The tool focuses on strategic portfolio methods, and includes simple financial portfolio methods (Section 3.3.3) that help decision-makers to think about future ways of income. **(1)** A score-card method (Table 15) helps fill in the relevant data and information regarding the innovation, and allows for the ranking of innovation projects (based on the information filled in) (Section 3.3.3). The ranking method is complemented with a **(2)** NPV indication, and the **(3)** Bang-for-Buck index to assist the decision-maker in making innovation selections based on budget restrictions (Section 3.3.3). **(4)** Bubble diagrams (Figure 26) and **(5)** strategic buckets help present the data and information to the decision-maker (Section 3.3.3). The methods help to visualise relevant information and the portfolio balance. The tool allows the user to customize the model (methods), so that the tool better integrates with the user's current innovation practices. Finally, the tool includes linkages to the external environment to co-development the tool, utilise external knowledge sources, and allow remote participation in the innovation portfolio management process for internal and external parties. The first viable management tool (IPM tool) still requires more iterations in its development, to help progress the model towards one that can be applicable to most innovation organisations.

SRQ5: What are the relevant criteria for an innovation support framework, that can adapt to the user's context and methodology and help position and integrate the innovation portfolio management model in current innovation management practices?

The innovation support framework (Figure 42), consists of six building blocks. The framework resembles a circle with layers and at its core **(1)** the organisation's strategy. The innovation process is illustrated as three activities: **(2)** idea management (Section 5.2), **(3)** development (Section 5.3), and the **(4)** launch and follow of innovations (Section 5.3.1). The innovation process can start at any point, and is continuous. The activities can be returned to and the knowledge they bring are stored so that they can be utilised for future developments. **(5)** The innovation portfolio management process links the organisation's strategy with the innovation process, by offering direction in the idea management process and frequently (Section 5.4) making sure the innovation projects are strategically aligned. The framework incorporates many information and knowledge linkages in the form of arrows, which illustrate how the processes influence each other. The innovation support framework also illustrates **(6)** the external environment as a circle surrounding the innovation process (Section 5.5). The circle includes information and knowledge linkages in the form of arrows, and illustrates that external data, information, knowledge, and stakeholders can influence the innovation process at any point in a positive or negative way.

The framework illustrates how the innovation portfolio management process can be positioned amid the other practices that influence the innovation process. It also shows the influences the external environment brings, and allows for the decision-maker to adapt to the information and knowledge that gets exchanged. Phases can be skipped or returned to, and the decision-maker can decide at any point whether an innovation project is still relevant or not and allow the project to move into another phase.

RQ **What are the four most important criteria for an innovation portfolio management model, that can adapt to the user's internal and external environment and integrate with the user's current innovation practices?**

An innovation portfolio management (IPM) model contains **(1)** a set of strategic innovation portfolio methods (Section 3.3.3 & 4.1) and is linked to the organisation's strategy, to have a reference point through which it can identify if innovation projects are strategically aligned. **(2)** The IPM model incorporates linkages to the innovation process and helps steering the idea generation process and idea screening process towards strategic alignment so that their development can be accelerated (Section 5.2). **(3)** The IPM model can identify and incorporate external sources of knowledge, information, and skills, in its analysis for risks and benefits and incorporates external parties in the screening and development of innovations (Sections 3.4.3, 5.4, 5.5, and 5.6). **(4)** The IPM model utilises decision support systems to acquire real-time information and knowledge (Section 3.4.4). The systems are complemented with knowledge management capabilities to utilise prior knowledge, on innovation success and failures, in the assessment of the innovation projects and innovation portfolio. These capacities, together with business intelligence, allow for the identification of similarities of current and prior innovation projects, to recognize incompatibilities and synergy (Section 5.6). The decision support systems allow the user to customize the innovation process to better integrate in its innovation practices, and reduce the complexity and resource intensity. As well as provide remote real-time access for decision-makers internally and externally to the organisation, to allow for feedback loops with relevant stakeholders before making the decision to terminate projects.

6.2 CONTRIBUTIONS

6.2.1 THEORETICAL CONTRIBUTIONS

Theoretical contributions to the existing knowledge landscape are discussed in this Section. The research presents the accumulation of knowledge on several fields of innovation and innovation management (Chapter 3) and illustrates the relationships between them in the form of a support framework (Sections 5.2-5.6). Several innovation management models were adapted based on suggestions made by their authors and other authors. The Stage-Gate model (Cooper, 2014a) fails to remains too sequential and lacks agility and flexibility. The innovation process is therefore split into three main activities (1) idea management, (2) development and (3) launch&follow. (1) The Stage-Gate model screens ideas on an individual basis, i.e. if the idea was perceived as financially attractive it would be developed. However, fails to address factors as budget restrictions and strategic alignment resulting in a short-term orientation in the organisation's innovation process. (2) Cooper (2014a) suggested to implement a build-develop-test process in the innovation management process. The build-develop-test, however, was presented as a linear and sequential process while the process takes place in an iterative manner where an activity can be skipped and the process would repeat itself until a satisfying result is obtained. (3) The Stage-Gate model assumes that every project is a product of its own and does not have any links to similar or previous products. The innovation process, however, is continuous and innovations build on innovations. Therefore, the innovation process was presented as a continuous circle and knowledge from innovations are stored and utilised in the next developments. The importance of external knowledge and information is highlighted through the visualisation of linkages to the external environment throughout the innovation process. And the innovation portfolio management (IPM) process was put parallel to the innovation process to illustrate that the IPM process can influence the innovation process at any point. The suggestions were based on studies performed which large sample sets from organisations active in different industries, and therefore would seem applicable for all innovating organisations. The framework presents the many interdependencies and relationships between the innovation management models and activities. The key elements from the perceived relevant innovation (management) models combined had not been illustrated clearly in previous research.

6.2.2 PRACTICAL CONTRIBUTIONS

First, the first viable innovation portfolio management (IPM) tool (Section 5.1) helps users to integrate the IPM process into their currently deployed innovation management practices. The tool is iteratively co-developed with lead-users lead-users and improving based on their feedback to help reduce the complexity and resource intensity of the tool. The *second contribution* is with regards to the innovation support framework and is made by illustrating the relationships between several innovation management models and activities. This provides the decision-maker with a better understanding of when and how the innovation portfolio management process needs to be performed. As well as the internal and external interdependencies for information and knowledge throughout the innovation process, so that the innovation decision-maker can consider these in his innovation management practices. *The final contribution* is made by illustrating the innovation process as a circle, for which its activities are continuous. This helps to emphasize for decision-makers that innovations build on innovations, and thus the knowledge and partnerships (knowledge sources) built or acquired throughout the innovation process need to be stored so that they can be utilised for future developments. This knowledge can help reduce the risks and resources surrounding the innovation process (Sections 3.4.3 & 5.3.1).

6.3 RESEARCH LIMITATIONS

To complement the findings, some of the encountered limitations are listed as followed. Firstly, the innovation support framework has not been tested in the intended user-environment. The reasoning behind this relates to the limited scope of this research. The research was conducted in six months, and does not only consist of requirements elicitation, but also of social research, technical design, and first demo development. The interviews were focused on the representatives of potential users of an innovation portfolio management tool, i.e. innovation managers, technical managers, CEO's and other executives from a diverse set of industries. It was very difficult to find the time and availability to schedule interviews with these representatives. This posed limitations and therefore there was no space for the test and validation of the proposed solutions. The relevance of the interview findings therefore is also quite low considering only one representative was interviewed from each industry (Appendix D: Interview list).

With regards to primary data gathering, there were several limitations resulting in an issue in the generalisability of the model. **(1)** Even though the case studies were exploratory in nature, they include limitations. For legal reasons, the group sample had to be limited to the client base of the two commissioning organisations rather than to a completely random one. The findings may be limited to these organisations. Although, efforts were made to maximise the diversity of the employee sample as much as possible, the sampling was limited by organisational affiliation. **(2)** Several interviews that included a validation process (Section 4.3), were performed together with the CEO of Critflow. The CEO was there to gauge the interest of the client and therefore might have biased the responses of the clients, e.g. regarding innovation portfolio management methods utilised or problems. **(3)** Exploratory interviews and validation interviews were only performed at eight organisations. More interviews might have resulted in better insights and improve the quality of the first viable IPM model (Section 5.1). This is due to the thesis scope and the limitation earlier mentioned regarding the legal reasons surrounding the research and difficulties encountered when arranging these interviews. **(4)** The fourth issue is with regards to how the research methodology might have hindered the research results. The researcher took the role of embedded researcher and thus knowledge was collected and created "on the ground", through daily interaction and negotiation with practitioners. The issue with this method is that it is partly biased, since the sample group is regularly in contact with the researcher and might be biased in the data they contribute. The researcher also simultaneously developed a solution for the commissioning organisations (SRO, Section 1.3) Based on these biases, the commissioning organisations might have also influenced the researcher into making certain decisions regarding the research progress. **(5)** Another limitation is given by the degree of completeness of this research. It is important to note that this is a fully qualitative research, with its most important findings coming from qualitative data, i.e. case studies. Case studies performed by others have been part of the research analysis. The quality of input for the analysis would have been higher if the organisations from these studies would have been interviewed as part of this research. The data might have been interpreted differently than it was intended when created. This issue was overcome to some extent by triangulating information. **(6)** Finally, the completeness of this framework is not claimed. The outcome of the research, the decision support framework, contains several building blocks that should be considered by the practitioners when performing the innovation portfolio management process. However, not all six building blocks were investigated in full depth. This is due to various reasons: the availability of respondents for the interview, the lack of information, and the thesis scope. Based on these factors, a lot of attention was dedicated to identifying the important factors for the positioning of the innovation portfolio management process in current innovation management practices. Furthermore, the focus of the research was mostly on the social aspects of the innovation management process and decision aiding process, and less on the technical aspects. The identified important technical changes were only mentioned.

6.4 Recommendations for further research

The research provides an innovation portfolio management model, and an innovation support framework to aid organisations in the innovation portfolio management process. To further develop the model, further research should build upon the following fields:

First, further research should be performed to help analyse to what extent the implementation of the proposed designs aid in solving the diagnosed problem. This involves (1) providing the innovation portfolio management tool (Section 4.1) to innovation decision-makers, and evaluating whether the tool improves their innovation portfolio management practice. This would also illustrate whether adjustments need to be made, to better cope with the user's criteria (regarding the complexity and resource intensity of the method). (2) Presenting the innovation support framework (Section 5.5) to innovation decision-makers, and evaluating whether the framework supports the decision-maker in the identification of how and when the innovation portfolio management process should be implemented (Section 1.2). The implementation of both artifacts should be monitored, to identify and indicate possible problems which could hinder the success of their implementation.

Secondly, as previously mentioned, this is a fully qualitative research. The intention was not to add quantification to this type of research, but rather provide an overview of the personal assessment on the completeness of each models researched (Chapter 3 and 4). However, it would be insightful to perform a quantitative research on how innovation decisions differ among a diverse sample set of organisations, by identifying their selection criteria and decision points through semi-structured surveys. This could yield a higher relevance of the innovation portfolio management model (Section 4.1) to the application environment, and beneficial to the adaptability of the model to better fit the context in which it would be implemented. This would also help determine whether the sampling limitations (Section 6.3), constitute a bias in the results when compared with random sampling.

Thirdly, the area of innovation portfolio methods remains unclear, i.e. it remains unclear which methods work well in which certain contexts and how the methods influence each other. More research is needed to identify the value of portfolio methods in the real-life environment and how they relate to each other as a set, to improve the adaptability of the model, better guide practitioners in their customization, and improve the project selection, resource allocation and strategic alignment.

Fourthly, more research is needed to validate the application of the CIM model as a communication framework using decision support systems in the innovation management process (Section 5.5). The methodology's contribution needs to be tested and validated.

Fifthly, the research proposes to separate the idea generation and idea screening process, to help involve the whole organisation in these processes (Section 5.2). While Tidd and Aleman (2016) proposed to include the whole firm in the process as a best practice, more research is needed to figure out if this serves a positive effect for the majority of firms in their performance and does not further complicate the innovation management process for practitioners.

Sixthly, the proposed segmentation of the building blocks (Section 5.5), and their intercorrelations and interdependencies still need further research. More research could highlight best practices of the proposed framework for certain contexts, such as industry type, innovation type. Gaining this knowledge would help to explain when and how certain processes and activities can be skipped throughout the framework in practice, resulting in a shorter time-to-market, and better efficiency (i.e. saving time, money and effort).

Finally, the innovation portfolio management model (Section 5.1) could be expanded into other fields and applications to help evaluate, score and rank alternatives. Examples of these would be: Investment Banking, Start-up Incubation, Resource Management, Project Management, Knowledge Management. These fields have several things in common with innovation management, including risk & reward analysis, resource allocation, technology transfers, long-term orientation. Further research is needed in these domains, to adapt the proposed solution to fit these fields.

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APPENDICES

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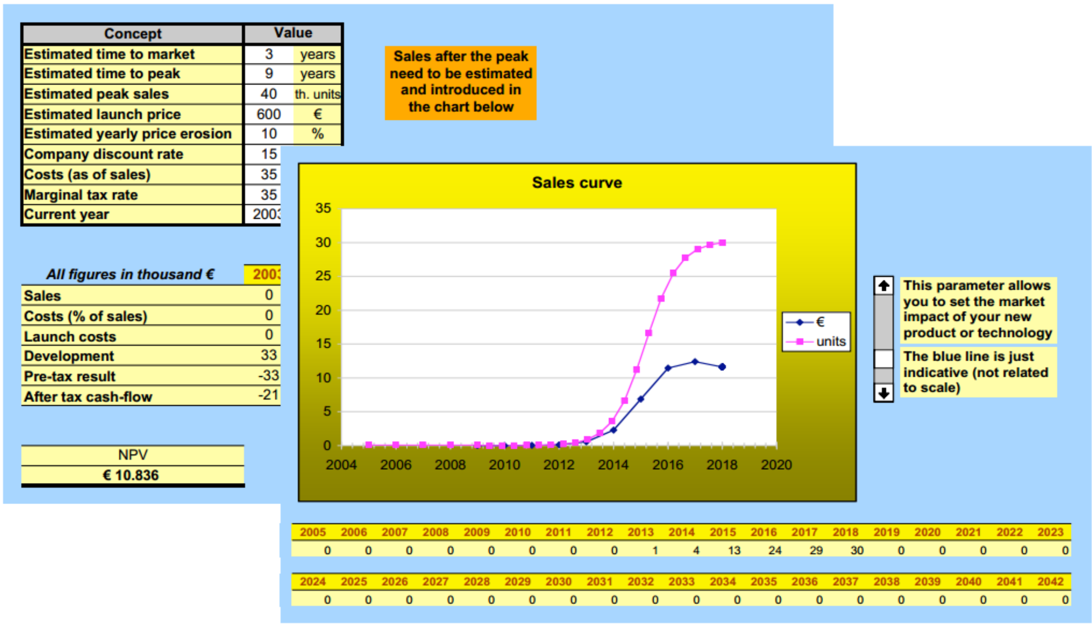
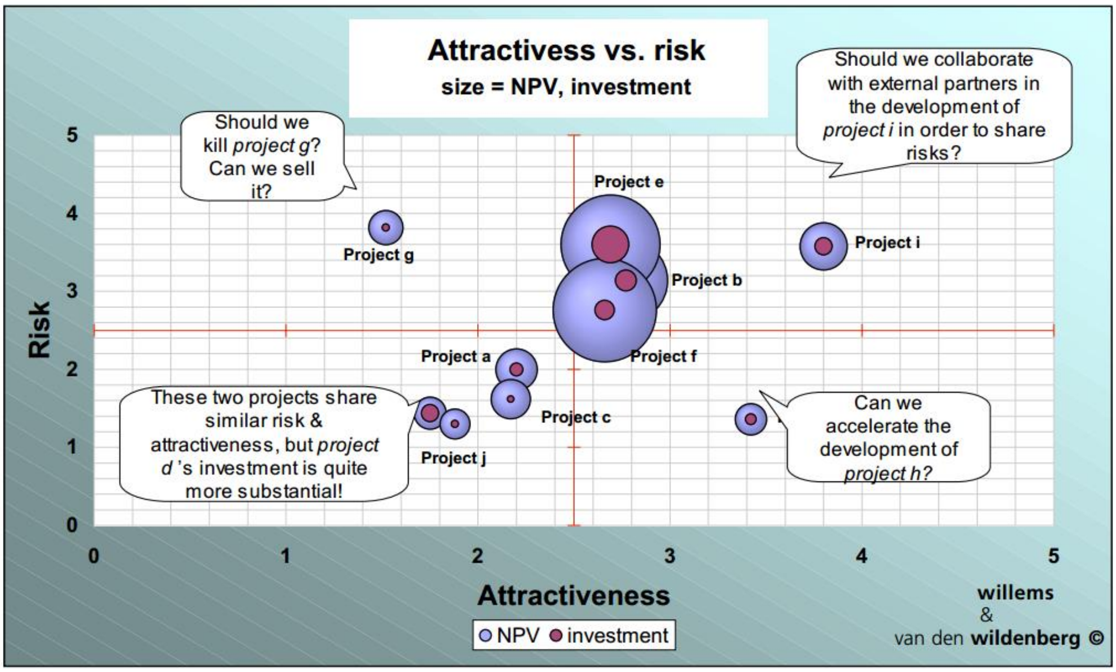
APPENDIX A: FUTURE CASH FLOW ESTIMATION

Project valuation: future cash flows estimation



APPENDIX B: BUBBLE DIAGRAM

Attractiveness vs. Risk



APPENDIX C: SCORING MODEL

Project name	
Person	
Position	
Date	
Project phase	

Area	Sub-area	Sub-area	Factor	Factor	Valuation			
Risk	Technological risk	0.2	Knowledge of technology	0.4	New to the wold	New to your company	Known to your company	Habitual to your company
			Expected development time	0.2	> 5 years	3-5 years	2-3 years	< 1 year
			Capability of available skills	0.1	< 40%	40-70%	70-90%	> 90%
			Phase of the project	0.2	Embrionic research	Research	Early development	Development
			Total cumulative negative cash-flow	0.1	> 3 million €	2-3 million €	1-2 million €	< 1 million €
			...					
			...					
	Market risk	0.8	Knowledge of market	0.3	New to the wold	New to your company	Known to your company	Habitual to your company
			Expected customer acceptance	0.1	Low	Substantial	High	Very high
			Number of entry in class	0.05	> Third	Third	Second	First
			Average annual growth rate of target market	0.1	< 0%	< 5%	10-15%	> 20%
			Price/performance compared to competitors	0.2	Low	Substantial	High	Very high
			Market openness to innovation	0.2	Low	Substantial	High	Very high
			Possibilities to exit market	0.05	Impossible	Hard	Medium	Easy
			...					
			...					
Attractiveness	Technological attractiveness	0.3	Makes a step forward in your technology roadmap	0.3	No	Moderate	Yes	Definitely yes
			Makes use of previous steps in your technology ro	0.1	No	Moderate	Yes	Yes
			Relevance of new technology	0.5	Low	Substantial	High	Very high
			Patenting chance	0.1	None	Low	High	Assured
			...					
			...					
			...					
	Market attractiveness	0.7	Sustainable competitive advantage	0.4	Low	Substantial	High	Very high
			Support to your corporate image	0.2	Low	Substantial	High	Very high
			In line with your market growth strategy	0.3	No	Moderate	Yes	Definitely yes
			Net Present Value (NPV)	0.1	<10 million €	10-20 million €	20-30 million €	> 30 million €
			...					
			...					
			...					

APPENDIX D: INTERVIEW LIST

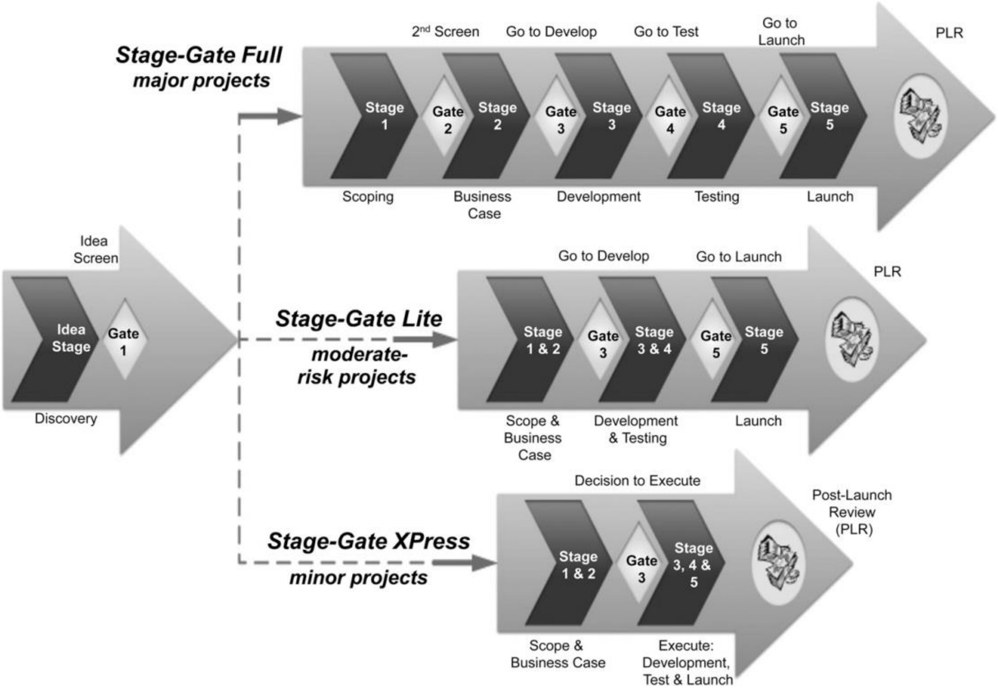
Interviews: Firms & External experts

COMPANY	POSITION	EMPLOYEES	REVENUE	PRIVATE / PUBLIC	PRODUCT	SERVICE	INDUSTRY	COUNTRY, LOCATION
IDIADA	Head of Innovation Innovation manager	1800	€ 133m	Private		x	Automotive	Spain, Tarragona
INDRA SOFTWARE LABS	Innovation management	39000	€ 3000m	Private		x	IT	Spain, Madrid
ZANINI	Innovation Program Manager	900		Private	x		Automotive	Spain, Parets del Vallès
INDO	Chief Innovation Officer	435		Private	x		Optics	Spain, Sant Cugat del Valles
FC BARCELONA	Innovation Strategist Innovation & Operations Manager		€ 650m	Private		x	Sports	Spain, Barcelona
SHELL	Innovation Subsidy Coordinator at Shell	94000	€ 421b	Private		x	Oil & Energy	Netherlands, Rotterdam
RIJKSWATERSTAAT	Head of Innovation & Market	9000	€ 4800m	Public		x	Government Administration	Netherlands, Utrecht
RIJKSWATERSTAAT	Corporate Innovation manager	9000	€ 4800m	Public		x	Government Administration	Netherlands, Utrecht

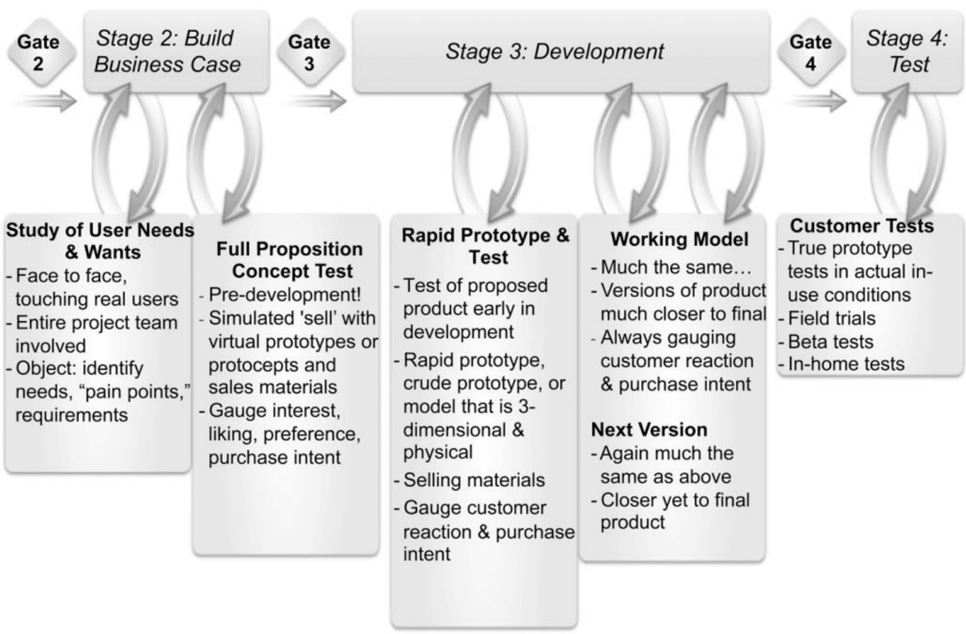
COMPANY	POSITION	PRIVATE / PUBLIC	PRODUCT	SERVICE	INDUSTRY	COUNTRY, LOCATION
UPC (EXTERNAL EXPERT 1)	European Projects Manager (past B&C consultant)	Public			Science	Spain, Barcelona
YOIN, MEDICAL DELTA (EXTERNAL EXPERT 2)	Partner at YOIN, Invest Manager at Medical Delta	Public / Private	x		Healthcare	Netherlands, Rotterdam
CRITFLOW	Founder & Managing director at Critflow Advisor at APPLIED SUSTAINABILITY GROUP	Private		x	Consultancy	Spain, Girona

APPENDIX E: STAGE-GATE DEVELOPMENT

Scalable Stage-Gate by Cooper (2014):



Spiral development feedback "Build-test-feedback-revise"



Appendix F: Design Requirements derived from the Theoretical domain

The design requirements in the following table were derived from what theory proposes (Chapter 5).

No	Requirement	Design requirement for artifact	Source
T1	To succeed in innovation, an organisation must possess the ability to acquire and utilize knowledge. Innovation is the continuous accumulation of knowledge and can be accelerated and improved through the incorporation of external stakeholders, by means of iterative feedback loops to better understand society's needs and concerns.	Facilitate linkages to external information and knowledge sources throughout the innovation process and allow for iterative prototyping, feedback, and testing with external parties during the innovation process.	(Barczak et al., 2009; Berkhout et al., 2006; Chesbrough et al., 2014; Von Hippel, 1976, 1986, 2001) **Section 3.1.2**
T2	For the creation of novel and more radical innovations, all four of the CIM knowledge and information cycles must be present. Current innovation models often only highlight the linkages to the user, customer and supplier.	Incorporate the CIM model to help identify and address all the relevant information streams, cycles and stakeholders throughout the innovation process.	(Berkhout et al., 2010) **Section 3.1.2**
T3	Innovation is a continuous process rather than a linear one, whereas learning and improvements occur in all stages. Phases can happen parallel to each other rather than being separated by management decision gates.	Highlight the permeable gates, many feedback loops, and linkages between the phases in the innovation management process.	(Berkhout et al., 2006, 2010) **Section 3.1.2**
T4	Innovations are linked to previous similar products and are not a product of their own.	Address the linkages between current and previous innovations (i.e. technology, information, stakeholders).	(Berkhout et al., 2006; Christensen, 2013; Schumpeter, 2013) **Section 3.1.2**
T5	Innovative ideas with potential value, should not be killed when the timing is wrong (i.e. not enough budget, knowhow, wrong innovation portfolio balance, customer cannot absorb the new technology now), but be stored to and revisited when its potential value can be obtained (e.g. through licensing, when the market is ready, when the complementary technologies are ready).	Address the storage of ideas and innovation projects and link the process to the innovation portfolio management and innovation management processes.	(Christensen, 2013) **Section 3.1.2**
T6	Idea generation and idea screening must not be limited to individual participation but also capable of being performed together with the 'whole' organisation and/or external stakeholders.	Separate idea generation and idea screening from the innovation (project) management process.	(Tidd & Thuriaux-Alemán, 2016) **Section 3.2.2**
T7	Iterative and spiral developments, such as the build-test-feedback-revise model (0Appendix E: Stage-Gate development), are often not linear in real-life and return to previous stages. In some cases (e.g. in IT) the process skips testing and puts the product on the market first (e.g. beta products).	Illustrate the build-test-feedback-revise as a development cycle and Introduce feedback loops in the cycle.	(Berkhout et al., 2010) **Section 3.2.2**
T8	Stakeholder relationships are seen to hold a distinctive competitive capability and therefore must be effectively managed (i.e. the recognition of stakeholders, positioning of stakeholder within the innovation project, storing and accessing previous collaborations, improving current relationships).	Address the integration of relationship management within the portfolio management process and innovation project management process to help manage and utilize the portfolio of relationships.	(Casper & Whitley, 2004) **Section 3.3.1**
T9	Organisations often develop multiple products in closely related markets, resulting in their innovations being developed showing synergy or incompatibilities and may complement or substitute one another.	Make interactions/linkages between technologies visual through KM and portfolio methods (e.g. technology roadmaps).	(Cooper et al., 2001b) **Section 3.3.1**
T10	Firms must decide at each phase of the innovation process, whether to continue, kill or change the resource allocation of an innovation project. The process of resource allocation, therefore, must be done frequently in a continuous manner and not be limited by the concept of phases.	Incorporate Innovation portfolio management and frequent portfolio reviews throughout the innovation process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.2**

T11	Innovation ideas and projects need to be evaluated individually and holistically (portfolio of innovations). And these two processes need to be closely aligned and need each other to properly function. Innovation portfolio (holistic) decisions must overweigh the other innovation management (individual) decisions.	Define and illustrate the relationship between Innovation project management and innovation portfolio management. And present Innovation portfolio management parallel to other innovation management processes.	(Alemán et al., 2015) **Section 3.3.3**
T12	External dynamics and changes (e.g. market transitions and trends) must be monitored and analysed throughout the innovation management process, to stop, kill or change resource allocation of innovation projects. In current gating models (e.g. Stage-Gate) this information is only reviewed at the decision 'gates'.	Address the linkages between the innovation process and relevant information sources external to the process. And present the external dependencies continuously throughout the innovation process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.1 & 3.3.3**
T13	Innovation portfolio management must include more than one innovation portfolio method with an average between two and three methods. These methods should complement each other.	Include two to- four complementing innovation portfolio methods in the IPM tool (see SRO, Sections 1.3 & 1.5).	(Cooper et al., 2000) **Section 3.3.3**
T14	The combination of innovation portfolio methods jointly must address all four major innovation portfolio goals.	Incorporate at least two out of the three innovation portfolio methods recognized by Coulon to do so (bubble diagrams, roadmaps, scoring models).	(Coulon et al., 2009) **Section 3.3.3**
T15	Financial portfolio methods perform the worst in terms of innovation performance, the focus should lie more on strategic portfolio methods.	Focus on strategic portfolio methods, rather than on financial portfolio methods.	(Cooper et al., 1999) **Section 3.3.3**
T16	The combination of innovation portfolio methods must be customizable (i.e. choosing methods, parameters, criteria, weights, labels) to better suit the context surrounding the innovation.	Address the ability of customization, by the user, within the innovation portfolio methods.	(Cooper et al., 2001b; Coulon et al., 2009; Phaal et al., 2006, 2004) **Section 3.3.3**
T17	Innovation portfolio management must be present in the process of idea generation or idea screening to select project developments and accelerate the process of reaching a portfolio balance.	Address the linkages of idea generation, idea screening and innovation portfolio management.	(Alemán et al., 2015) **Section 3.3.3**
T18	To perform innovation portfolio management and help align innovation projects with organisation's strategy, the strategy needs to be defined prior to the process and revised when needed. It is important to create a common expectation and understanding about what should be achieved through the process.	Incorporate the innovation strategy and link it to the innovation portfolio management process.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.3**
T19	Innovation portfolio management reviews should include the following three practices: definition and revision of the strategy, optimisation of the existing portfolio, and selection of new projects.	Address the three best-practices performed in innovation portfolio reviews.	(Alemán et al., 2015; Cooper et al., 2001b) **Section 3.3.3**
T20	Innovation decision-making differs per organisation and even per innovation project, therefore the innovation management model must include flexibility in the roles and decision structure within the organisation to better suit the innovation environment.	Address the customizability and adaptability of Innovation management models to the innovation environment (organisation, innovation project, external context).	(Cooper & Edgett, 2008) **Section 3.4.1**
T21	Linkages to external data and knowledge platforms (such as subsidy opportunities, knowledge and skills services) must be incorporated into the innovation management decision support system to help reduce and share the risks of innovation.	Integrate data and information gathering linkages throughout the innovation process.	(Turban et al., 2006) **Section 3.4.4**
T22	Utilise computerized (group) decision support systems to allow for remote group decision-making, by facilitating information and helping decision-makers elaborate and justify their suggestions and opinions.	Incorporate computerized (group) decision support systems to facilitate the many linkages and iterative feedback loops through which knowledge and information is exchanged throughout the innovation management models.	(Cooper et al., 2001b; Turban et al., 2006) **Section 3.4.5**
T23	Knowledge management systems are needed to store, access and utilise knowledge throughout the	Address knowledge management systems as a complement to decision support systems.	(Turban et al., 2006)

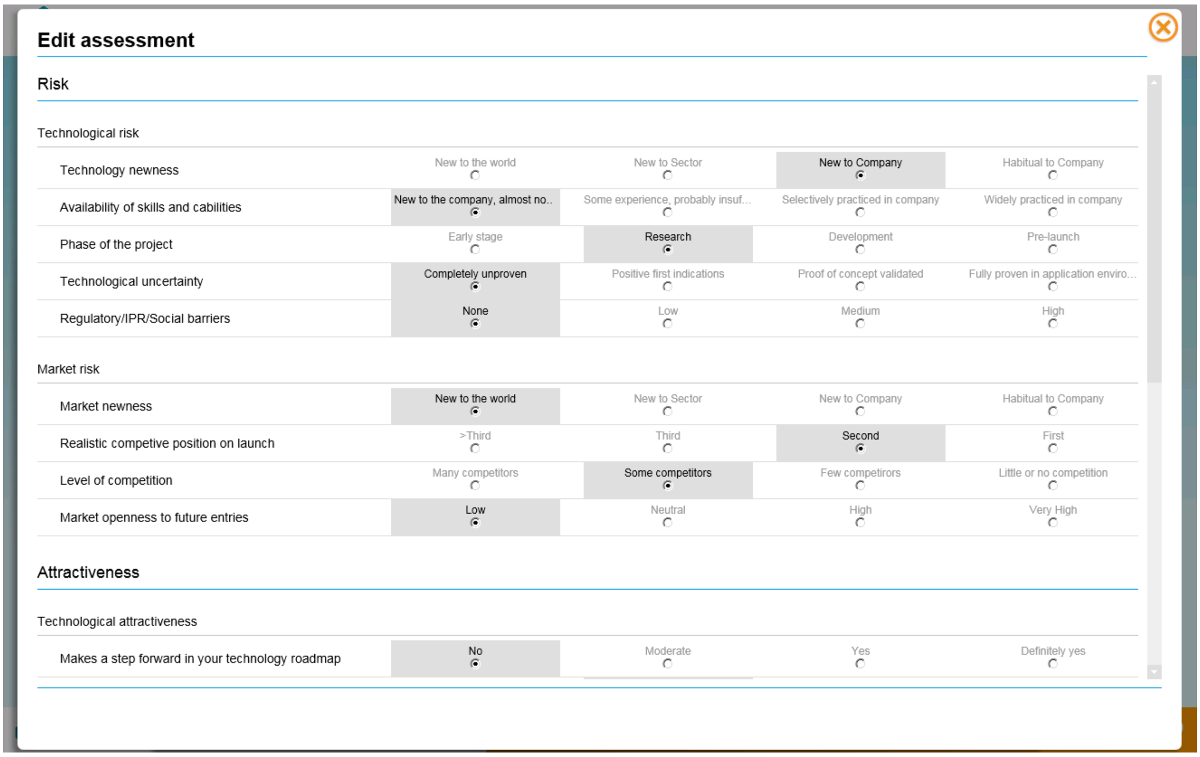
	organisation and help share and disperse this knowledge for maximum organisational benefit (see Design requirement 1).		**Section 3.4.4**
T24	To reduce the resource intensity, decision support systems should include a level of intelligence to help (1) scan the internal and external information sources for problems and opportunities, (2) identify relevant stakeholders, (3) identify relationships among projects, technologies and stakeholders, (4) identify similarities with past situations through knowledge management systems and how to handle these.	Address the benefits and importance of business intelligence within decision support systems.	(Turban et al., 2006) **Section 3.4.5**

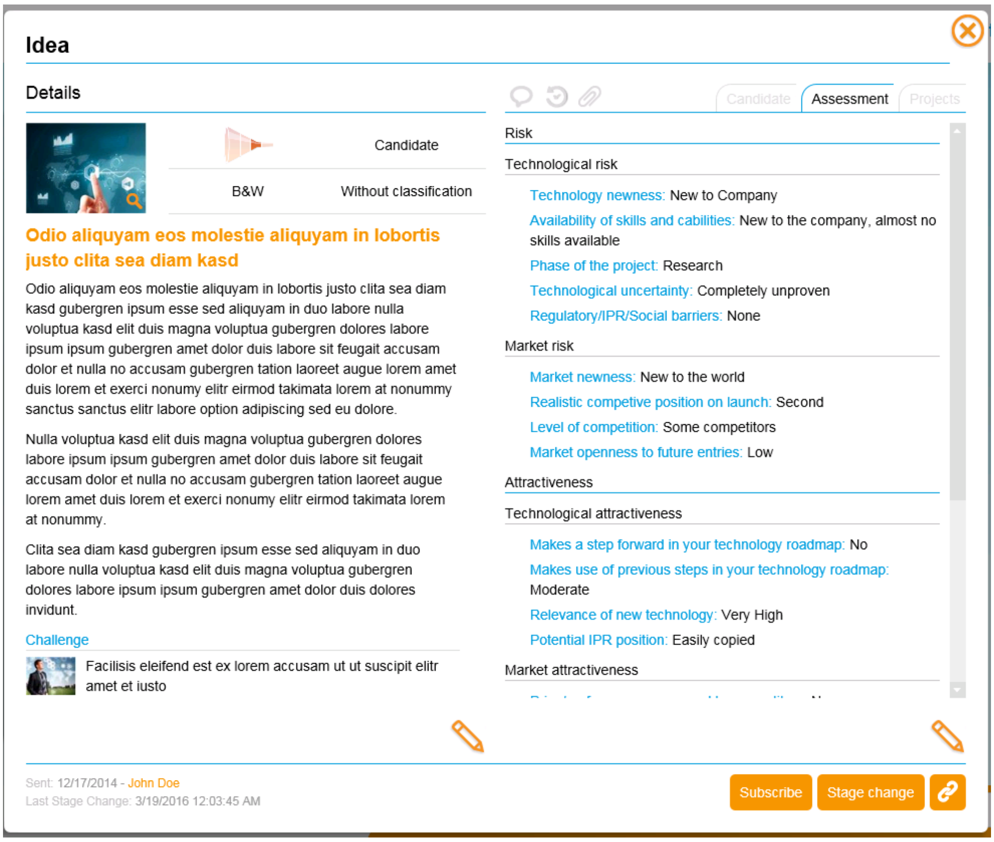
Appendix G: Practical requirements

The following design requirements (table below) were obtained from external experts and innovation managers in the application domain through case studies (Chapter 4).

Design requirements obtained from case studies		Source
P1	The model must include methods for remote participation in the innovation portfolio management process.	External Expert 1 **Section 4.1**
P2	Lead-users should be involved in the development (e.g. through toolkits)	External Expert 1 **Section 4.1**
P3	Innovation portfolio methods must be interactive (i.e. changes should be instantly visible), fast and able to display a number relevant data without complexifying the visuals.	External Expert 1 **Section 4.1**
P4	Avoid financial methods	External Expert 1 **Section 4.1**
P5	Focus on introducing Strategic methods	External Expert 1 **Section 4.1**
P6	The IPM model and methods must be customizable to better fit the user's needs and environment without the need for external involvement. The users must be able to adapt the model for a better fit with their internal structure and processes, and the dynamic external environment.	External Expert 1 **Section 4.1**
P7	The innovation management model must be capable of storing and sharing (of required) knowledge and information. This includes the identity of internal and external stakeholders, their roles, and their contribution	External Expert 1 **Section 4.1**
P8	Define organisation strategy (focus) up-front and revise when needed	Critflow **Section 4.2**
P9	Translate strategy to strategic and corporate goals (challenges) to help steer ideation.	Critflow **Section 4.2**
P10	Allow for executives to pull (unselected) ideas through the voting process to help reach portfolio goals.	Critflow **Section 4.2**
P11	Allow for the involvement of the whole organisation in the generation of ideas and screening of ideas, to create more novel and creative ideas, and reach more engagement from employees.	Critflow **Section 4.2**
P12	Projects must be followed throughout their existance to adapt to new internal or external insights, knowledge and information.	Critflow **Section 4.2**
P13	The knowledge and information gained through the innovation must be stored so that it can be accessed and utilised for future innovations.	Critflow **Section 4.2**
P14	Periodically the ideas and projects must be analysed and made visual in charts to help decision-makers identify their key performance indicators, such as the strategic alignment or financial benefits they bring, and help keep the portfolio balanced.	Critflow **Section 4.2**
P15	Ideas that don't get selected must either get archived or frozen to be utilised another time or in different manners (e.g. through licensing or sale).	Critflow **Section 4.2**
P16	Customers must be included in the innovation decision-making process, before making decision to continue or kill projects.	External Expert 2 **Section 4.3.1**
P17	The possibility and effect of sharing risks with external partners for long-term innovation projects need to be addressed.	External Expert 2 **Section 4.3.1**
P18	Address the important presence of established relationships and the need to share in-house technologies and strategies.	External Expert 2 **Section 4.3.1**
P19	Incorporate the mapping and linking of innovation portfolios with their technologies (technology mapping) to help identify and utilise innovations.	RWS **Section 4.3.1**
P20	Incorporate intelligence in the decision support system to reduce the resource intensity of the model	External Expert 2 **Section 4.3.1**
P21	There should be a simple estimation for future income, e.g. NPV	External Expert 1 **Section 4.3.1**
P22	When using portfolio scoring models, introduce four options. Since most users are uncertain, they tend to choose the middle option leading to invaluable results	External Expert 1 **Section 4.3.1**
P23	Incorporate a method that allows for innovation project selection based on budget restrictions (e.g. Bang-for-Buck)	Zanini **Section 4.3.1**

APPENDIX H: IPM TOOL DIGITAL INTERFACE





APPENDIX I: EASYCRIT INNOVATION PROCESS