Royal Philips

Strategic Architecture Valuation

A method to quantify investment decisions in product architecture based on real option theory

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Management summary

When a company creates a product architecture, it needs to decide about available technology and market opportunities. These decisions are usually hard to make because the financial implications to the firm are often significant and uncertain. Strategic Architecture Valuation was developed as a practical method in order to quantify these financial effects and thus improve the way product architectures are created.

The method identifies four strategic decisions. For instance, a promising new technology can be included in each product already (1) or an interface could be created to get a fast time to market (2). The company could also discard the possibility for the technology (3) or postpone the decision and redesign if necessary (4). Each decision has its financial impacts on both costs and time, which are indicated in the figure.

In addition to the decisions, some basic market estimations are needed from the user. Based on that the net profit of each decision is determined. Every number can be inputted as a range or as a fixed number. This makes it possible to quantify the decisions, whilst considering uncertainty of the future. In addition future managerial choice is modelled for some decisions. Because of its resemblance to option theory from the financial market this inclusion of uncertainty and choice is referred to as options thinking.

The method is built to be practical. It was tested at Philips AppTech and applied at three cases. A typical case can be modelled within the hour. Because of its implementation in Excel, the method is flexible enough to model case specific behaviour if needed. Results show the impact of each decisions on the company and also show the uncertainty of the outcomes. It can therefore be used to stimulate discussion between departments and increase the insight in financial effects.

Preliminary reactions to the method are positive. However there still lie opportunities to test the method in additional cases and to investigate its use in other disciplines such as portfolio management.

Preface

This masters thesis is the result of the my final project for the study Business Administration at the University of Twente. During the last eight months I have had a good time doing my research at Philips. Living in a Philips home with other interns was fun, although I sometimes felt like an exchange student because I was the only Dutch guy! Coming from a mechanical engineering background, I had to get accustomed to a different way of doing research. Probably because of the combination of this study and my engineering background, the result did not turn out to be stereotypical work of Business Administration students. This was only possible due to the open minds of my supervisors. For this I would like to thank them all. In my view it was a pleasant cooperation between all of us.

Individually, I would like to thank ir. Hissel for the endless hours we spent together discussing and thinking about the method and giving me the opportunity at Philips. You put a great deal of effort in the work as well, which I highly appreciate. We had a fun time.

Additionally I would like to thank Ms. dr. Beerkens for the guidance she gave me when I was felt stuck again in my research. It really helped me. You spent way more time on me than required: thanks for that.

My thanks go as well to prof. dr. ir. Wouters for his enthusiasm and way of motivating me to really create something valuable. Even when handed limited information, your suggestions were often spot-on.

During my project many people at Philips helped me to discuss the method or apply it in a case. Some of them spend many hours on this. For this I would like to thank them all very much.

Mark Workum

How to read this thesis fast

The following sequence describes fastest way to learn the method, skipping most of the theoretical background and considerations. Please do note that this skips big parts of theory, including option theory. For a thorough understanding, read the entire thesis.

- Management summary (if you haven't done it already)
- Chapter 1. An introduction to product architecture and challenges p.p. 10 and the goal on p.p. 11
- Chapter 4. Decision tree analysis p.p. 32-37
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    - The four decisions in a decision tree p.p. 54 to results of an example case p.p. 74
- Chapter 6 entirely

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Where facts are few, experts are many – Donald R. Gannon

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Chapter 1 Project introduction – Philips wants architecture based on the facts

Project motivation

This research originated from the need at Philips Applied Technologies (hereafter Philips AppTech) to improve the financial insight in decisions regarding product architecture. The following section describes the motivation of the problem at AppTech. First, the field in which AppTech operates is introduced briefly. This is followed by sections that introduce the concept of product architecture and its relation to Philips AppTech.

An introduction to Philips AppTech

Philips Applied Technologies is part of Royal Philips Electronics and supports its customers by applying advanced technologies. These customers include both business units (hereafter BU's) within Philips and external companies. Philips AppTech is divided into several divisions. Exhibit 1 depicts the organizational structure.

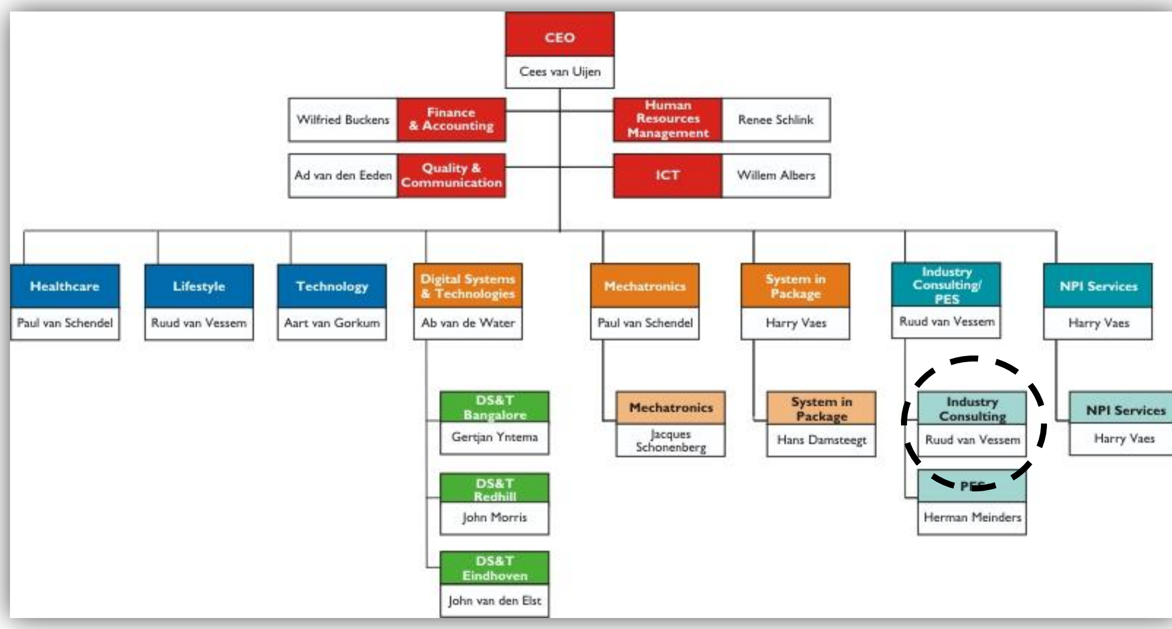

Exhibit 1 – Organizational chart of Philips Applied Technologies. The Industry Consulting division is highlighted.

The Industry Consulting division operates within Applied Technologies and offers consultancy services on processes in product creation, industrialization and business realization. The division was originally set up to share the technical business knowledge within Philips Electronics. Later on the division evolved in providing consultancy services. Because of its long history of acquiring technological knowledge, Industry Consulting offers advice on many topics on innovation and operation management. Some illustrative examples of the solutions they offer are stated below.

- R&D portfolio management
- Product creation process management
- Product, Market and Technology road mapping
- Supply chain management
- Outsourcing and allocation issues
- Lean manufacturing

Services from Industry Consultancy also include advice on product architecture development. The research focuses on this topic.

An introduction to product architecture

Roughly formulated, product architecture is the design and layout of physical building blocks of a product. Since every product is made of physical building blocks, every product has a specific architecture. Thus, one could speak of the architecture of a shaver, a television or vacuum cleaner and simply refer to the way it is decomposed. In many occasions it is possible to design a product in numerous ways. Since this leads to a different design of the components, all of these designs will have a different architecture. Abstract terminology is used to refer to properties of components in products and the way they interact. This makes it easier to evaluate different architectures.

Product architecture can be of strategic importance to a company, since adjustments in the design of a product can have a major influence on the business performance. For instance, a product can be prepared for future product variants, or share components with other products. This way a product architecture can open significant sales opportunities or cost reductions for the company. Chapter 2 will discuss product architecture and its strategic relevance into more detail.

Product architecture challenges at Philips AppTech

Benefits from product architectures usually do not occur spontaneously, but need to be created in the architecture deliberately. However, in a lot of firms the product architecture is simply determined by R&D and important strategic decisions *may be made not by intention, but by default* (Krishnan, et al., 2001). Specialized consultants from Philips AppTech apply their architectural knowledge within Philips and at external customers to improve their product architectures and the architecture creation process.

During preliminary interviews, these consultants identify multiple causes of the problems in creating good product architectures in most companies.

One major cause is the struggle to get all business functions to work together. In order to improve cooperation in architectural decision making, Philips AppTech developed the so-called *Architecture Framework*. This was published in R&D Management (De Weerd-Nederhof, et al., 2007), (Zwerink, et al., 2007). This framework is qualitative and holistic in nature. It has been applied at customers and was combined with an introductory questionnaire and a workshop. The usefulness of the framework was evaluated amongst five cases (Teuns, 2005). Although the qualitative framework was a useful tool to map the architectural decisions on various business functions, the evaluation indicated a need for a financial quantification of these decisions.

Philips AppTech explicitly indicates the need for quantitative approaches to use in real life situations. Therefore, the practical use of the outcome of this study will be of high importance. Because of the complex nature of the effects of product architecture, this is not a trivial matter. Accordingly, there will therefore be a strong design focus in this study.

Goal formulation

Considering the problem background, the goal for this study is formulated as follows.

> To improve the joint creation of product architectures, by developing a practical method

Practical method: A practical method is defined as a method which is either directly or relatively easily applicable to real life cases encountered by practitioners in product architecture

Financial effect: A financial effect is defined as a variable which has a significant and quantifiable effect on either costs or revenues and is caused by an choice in product architecture

Choice in product architecture: A choice in product architecture is defined as a consciously made decision in the design of a product architecture

Joint creation: Joint creation is defined as the creation of a product architecture by multiple business functions whilst taking their requirements and interests into consideration

Central questions

In order to attain the formulated goal, a number of central questions need to be answered. These questions are stated below.

1. What are the requirements for the method?
2. What is the current state of the art in valuating decisions in product architecture?
3. How is the method shaped?
4. Does the method meet the requirements?

The meaning of some central questions is rather intuitive, whilst others may need some clarifications. Therefore, the questions are discussed briefly in the following sections.

Q1: What are the requirements for the method?

In order to develop a method, requirements need to be established. Prior to this, a general understanding of the problems in product architecture creation is needed, which makes this research constructive in nature (Kasanen, et al., 1993). Therefore a profound effort is put in a problem analysis on joint product architecture creation. Requirements are made based on this analysis.

The requirements form the basis of the evaluation of the method, i.e. it defines the criteria to judge whether or not the new framework is a good one.

Q2: What is the current state of the art in valuating decisions in product architecture?

An assessment of the current state of art enables the reuse of existing knowledge and identifies knowledge gaps that need to be addressed. Known approaches from scientific literature and from Philips AppTech will be examined for this purpose.

Q3: How is the method shaped?

A description of the method is needed to enable the reader to understand and reproduce it. This includes reasons why the method is made in a specific way. Therefore the method is tested in real life cases.

Q4: Does the method meet the requirements?

The method needs to be evaluated to determine if it reaches the goal. Therefore a conclusion will reflect on the predetermined goal and requirements.

The structure of this thesis

This thesis is structured in the same way as the research approach of this study. This research approach is depicted in Exhibit 2.

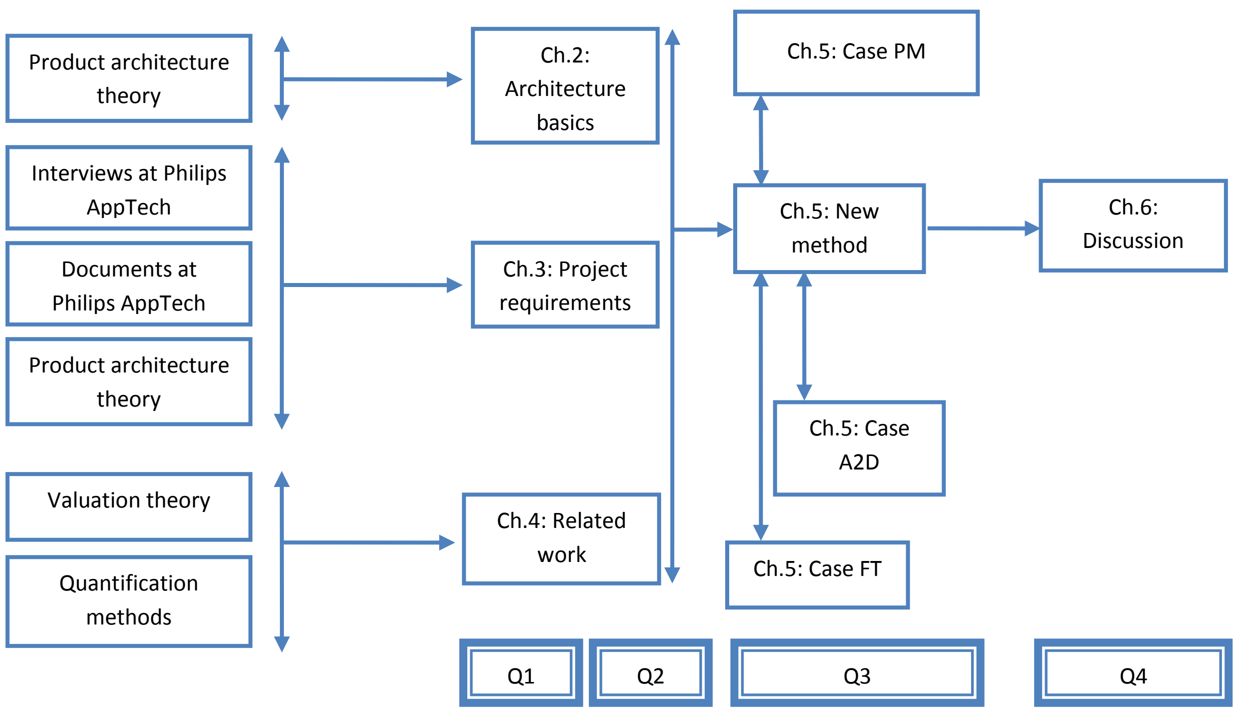

Exhibit 2 - Research approach of this study

Product architecture theory will first describe the basics in product architecture and it strategic relevance (Chapter 2). Then project requirements are made, based on interviews at Philips AppTech, documents at Philips AppTech and product architecture literature (Chapter 3). At this point central question 1 will be answered. Then known methods in literature and at Philips AppTech are examined together with valuation theory (Chapter 4). This answers central question 2. The findings will be used to develop a new framework, which is tested using case applications. This answers central question 3. Finally, conclusions about the framework will be made regarding the requirements answering central question 4 (both in Chapter 5). The method is discussed in Chapter 6.

Chapter 2 Product architecture basics

Introduction

The current chapter discusses the basics of product architecture and shows the strategic relevance it has to the firm. The chapter is meant to get an understanding of product architecture and does not answer a central question.

The definition of product architecture

Roughly formulated, product architecture concerns the design and layout of physical building blocks of a product. Since every product is made of physical building blocks, every product has a specific architecture. Thus, one could speak of the architecture of a shaver, a television or vacuum cleaner and refer to the way it is designed.

Product architecture is an abstract way of looking at a product and it is usually determined before a product is actually designed into detail (Ulrich, et al., 2000). Likewise, abstract terminology is used to refer to properties of components in products and the way these components interact. This makes it easier to evaluate different architectures in an early stage of the product creation process. The concept of architecture is not restricted to products, but can be found in a various other domains, such as software architecture, process architecture and even business architecture. Thus, architecture is an abstract way of looking at a design in general.

Multiple definitions exist of architecture (Simon, 1962) and of product architecture specifically (Henderson, et al., 1990), (Van Wie, et al., 2001), (Fixon, 2005). Most of these definitions have minor differences in formulations, but are in essence the same. However, the first (and most widely accepted) explicit definition of product architecture is by (Ulrich, 1995). He defines product architecture as *"the scheme by which the function of a product is allocated to physical components"*. More precisely he specifies product architecture as:

1. The arrangement of functional elements
2. The mapping from functional elements to physical components
3. The specification of the interfaces among interacting physical components

The coming section will illustrate the key concepts in product architecture briefly using an example. Unless otherwise stated, this thesis will adopt the definitions from (Ulrich, 1995).

Key concepts in product architecture

The key concepts will now be illustrated by comparing two architectures: that of a car and of a motorcycle. These architectures are depicted in Exhibit 3.

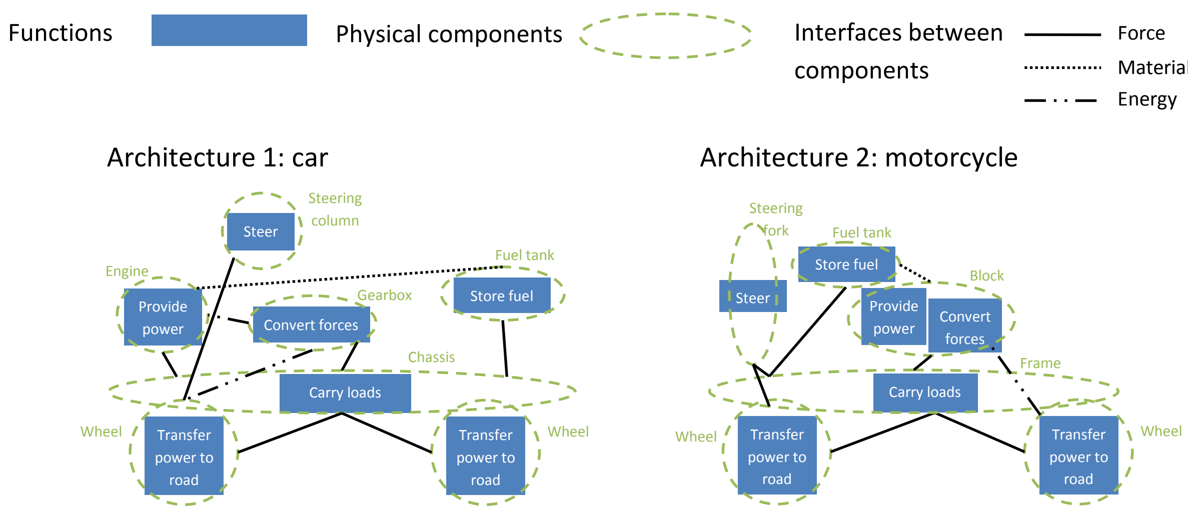

Exhibit 3 – Product architectures of a car and a motorcycle

Exhibit 3 shows the key concepts in product architecture, i.e. functions, components and interfaces. Notice how product architecture makes it easy to compare different design alternatives before a product is actually designed into detail. For instance, both architectures share the same functions. Functions are things a product actually does. In the example functions include provide power, store fuel and carry loads and are indicated in rectangles. These functions are then implemented into physical components. For instance, in both architectures fuel is stored by the fuel tank and power is transferred to the road by the wheels. These components are depicted by dotted ellipses in the figure.

Interfaces exist between different physical components. These interfaces can be of different natures, such as the transfer of force, material or energy (other classifications exist as well, but are not relevant for this thesis) . For instance the engine in the car has a force interface with the chassis since it supports its weight. A rotating axle creates an energy interface between engine and gearbox and fuel flows from the fuel tank to the engine through a material interface. The degree of coupling is an importance characteristic of an interface. *"Two components are coupled if a change made to one component requires a change to the other component in order for the overall product to work correctly".* (Ulrich, 1995). Thus, the fuel tank and the engine are loosely coupled. After all, a change in the fuel tank usually does not imply changes in the engine since they are connected with a simple hose. However, the fuel tank and chassis or frame are coupled tightly since a change in dimensions of the fuel tank may make it impossible to fit anymore. The degree of coupling is important to define modularity.

Modularity is a classification which gets a lot of attention by academics because of its strategic importance and managerial implications, e.g. (Baldwin, et al., 2000), (Gershenson, et al., 2003), (Mikkola, et al., 2003),(Sanchez, 2000). *"A modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product, and specifies de-coupled interfaces between components"* (Ulrich, 1995). Non modular components are often called integrated. For instance, a dashboard in a car (not depicted in the example) has multiple functions like providing looks and holding objects. Furthermore, it has a huge amount of interfaces with other components that are tightly coupled on dimensioning, such as buttons, the doors, the windshield, the mid console, etcetera. Changes in other components likely affect the dashboard. Therefore we call this an integrated component. On the other hand, the engine is more modular. After all it only includes a single function and has strictly specified interfaces with its other components. It is therefore relatively easy to change other components without having to change the engine. Modularity can enable specific design benefits that might benefit the company, like sharing components amongst various products (called commonality), or creating product platforms.

The strategic importance of product architecture

The architecture of a product can be of strategic importance to a company, since adjustments in the design of a product can have a severe influence on the business performance. One of the most obvious influences is the possibility for cost reduction. For instance, a product could be designed in an assembly friendly way enabling fast assembly. Furthermore, a good product architecture can lead to sales increase as well. For example, an architecture can already include an interface for future technologies, so the new technology can be implemented fast once the market demands it. However if a product is not prepared for a new market, redesign can be much more expensive than anticipating for it in advance. Therefore neglecting these options early in the product development phase may have profound implications on the business. Because of this strategic element, some refer to modular architectures as strategic options (Sanchez, 1996), (Sanchez, et al., 2001). Since technologies are changing increasingly fast and product life cycles keep on shortening, the time for business managers to react to competitors' moves and new technological opportunities keeps diminishing. This makes a good product architecture a necessity rather than a luxury. Although many managers do not yet realize it, *"the success of whole strategies may hinge on such seemingly minor details"* (Baldwin, et al., 1997).

To illustrate the strategic importance of product architecture, Exhibit 4 shows an example of the redesign of the architecture of the Philishave shaver at Philips. In the old designs, every shaver was more or less designed separately according to individual product specifications. This resulted into many different parts which had an impact on manufacturing, the warehouse and logistics. By assessing the market and technological developments, Philips realized that market developments in shaving usually involve a change in the shaving head and exterior design. Other requirements however remained fairly the same. Therefore Philips created a new architecture that included an inner part that integrates all common internals like the DC motor, gears and battery pack. Interfaces between the inner part and the design panels and shaving head were specified thoroughly to ensure a loose coupling between shaving head and design panels.

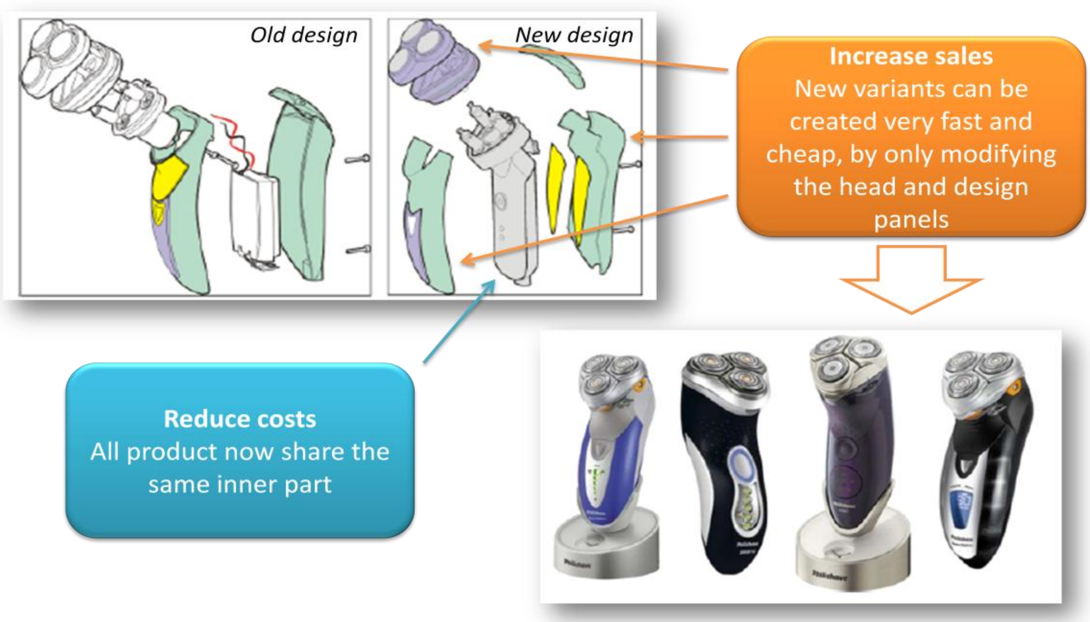

Exhibit 4 – The strategic product architecture of the Philishave

The new architecture has significant benefits to Philips. It reduces costs dramatically, since all Philishaves now share the same integrated inner part. Furthermore, the new architecture enables Philips to create new product variants very fast and cheap, since it only requires a modification in the design panels and shaving head. This increase in time to market offers Philips a competitive advantage.

There are multiple ways in which strategic capabilities can be implemented in a product architecture. However, many see modularity and commonality as the major strategic choices to be made, e.g. (Sanchez, 1996), (Baldwin, et al., 1997), (Sanchez, 2000), (Sanchez, et al., 2001), (Garud, et al., 2003), (Ulrich, et al., 2000). This can also be seen in the Philishave example. The inner part is a commonality and reduces costs, whilst the modular head and design panels create product variety.

Chapter 3 Project requirements

Introduction

The current chapter of this thesis answers central question 1. This question is repeated below.

Q1: What are the requirements for the method?

This chapter consists of two parts, i.e. the problem analysis and the project requirements. The problem analysis investigates the problems in creating product architectures more profoundly. It forms the basis for the project requirements that will be stated at the end of this chapter and answers the first central question.

Problem analysis

The problem analysis is based on taped semi-structured interviews at Philips AppTech, documents at Philips AppTech and academic literature. Furthermore, many informal meetings were held with employees at Philips AppTech. The entire process took roughly one month. Exhibit 5 states the object that is investigated and the used sources of information.

Goal		
To investigate the problems in joint product architecture creation		
Research object		
The joint product architecture creation process		
Source of information	**Type and number**	**Method of investigation**
People at Philips AppTech	Product architecture experts (2)	Semi-structured interviews
	Architecture experienced employee (1)	Semi-structured interviews
Documents at Philips AppTech	Case descriptions (3)	Content analysis
	Unprocessed data from the evaluation of (Teuns, 2005)	Content analysis
Product architecture literature		Database search

Exhibit 5 – Research information of the problem analysis

People are the primary source of information for the preliminary research, because they have a high diversity of information and provide a relative fast way of obtaining information (Verschuren, et al., 2007). Because of practical considerations the sample is restricted to three persons at Philips AppTech.

Since the limited sample can endanger the external validity, the problem is also examined in literature and in documents at Philips. This practice is known as triangulation.

All information was structured in a causal map to identify the key problems in creating product architecture. The map is a graph of elements in which an arrow indicates causality. A causal map is used in this case since it facilitates finding improvements in operations research, particularly if the information is complex or hard to grasp (Eden, 1988) (Eden, 2004). It is depicted in Exhibit 6. Theme clustering and central statement identification were used to isolate the essence of the problem (Eden, 2004). Since the results are merely used to derive requirements for the method, the map is not intended to be fully comprehensive nor conclusive.

The analysis concludes that **practical quantification is likely to improve product architecture creation** in two ways. First, practical quantification stimulates business function cooperation. Secondly, it improves the financial insight in architectural decisions. The current section elaborates why these areas are likely to improve architecture creation and how this can be stimulated by practical quantification. The section will adopt the structure of the causal map.

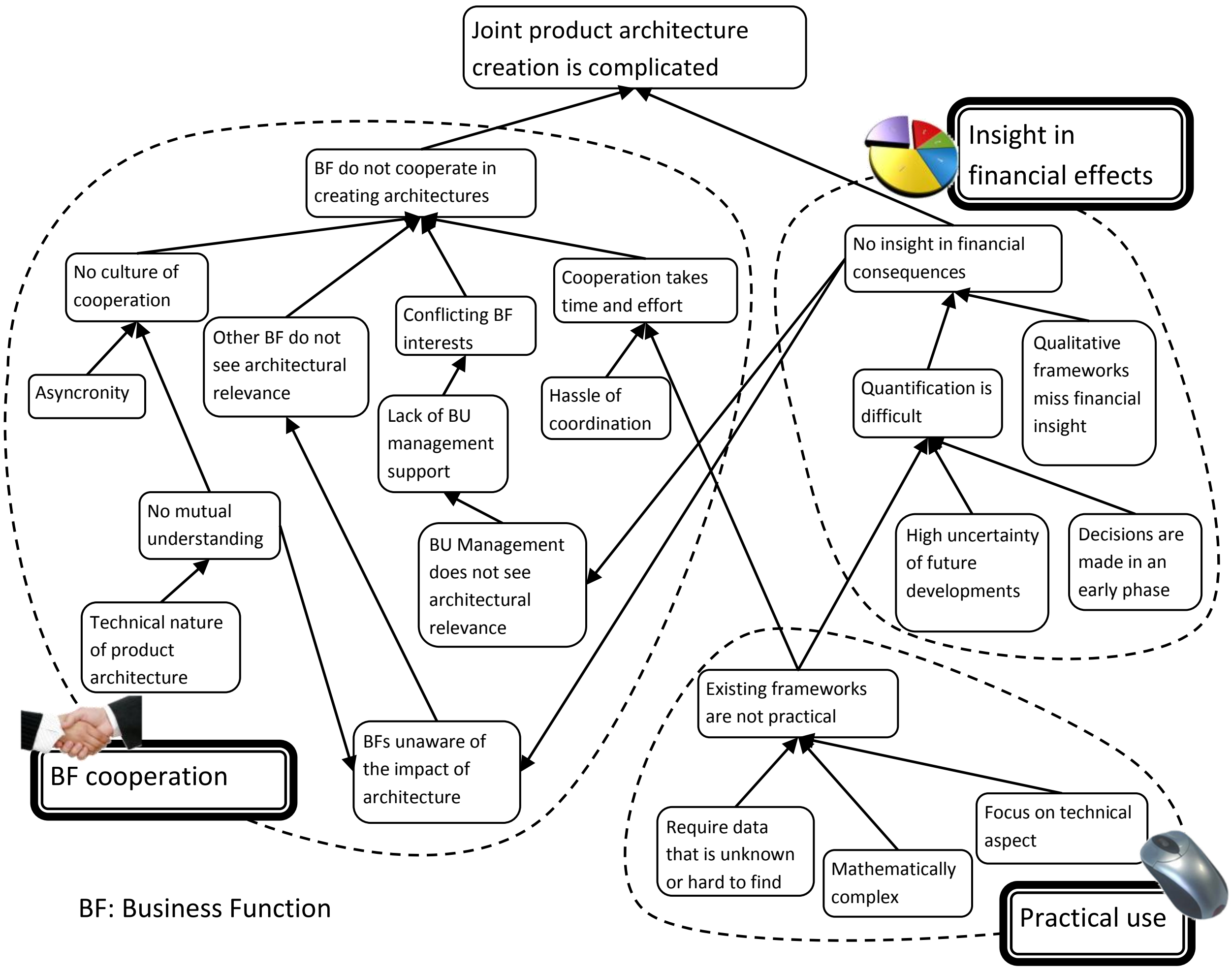

Exhibit 6 - Causal map of the problem analysis

Business function cooperation

Philips AppTech indicates an important role for the cooperation of business functions in creating successful product architectures. After all, R&D always designs products based on requirements from other business functions. If the interests of all relevant business functions are not taken into account, the product architecture may turn out totally wrong. As one respondent expressed it, *"if there are some flaws [in very important inputs] you might be implementing the WRONG things in a very good way"*. Unprocessed data of five cases from the evaluation of the Architecture Improvement Method (Teuns, 2005) confirm this as well. To a various extent participants desire a *"multidisciplinary team"* and *"marketing involvement"*.

The academic literature shows little about the creation of product architecture itself, let alone about the role of business function cooperation. Instead, many studies investigate the effects of product architecture on a firm[1]. (Yassine, et al., 2007) confirm this: *"there is a general lack of empirical studies about how architectural decisions are actually made or how information that influences the architecture actually flows"*. However, some studies implicitly show the need for research on cooperation in product architecture. For instance, (Fixon, 2007) pinpoints interesting topics for further research on product architecture including *"studies that incorporate modularity and commonality's multiple effects **on various players along the supply chain**"* (my emphasis). Likewise, (Jiao, et al., 2007) emphasise the role of the market by addressing the need for *"customer integration"* in product family design. In addition, literature in other areas than product architecture show the importance of business function cooperation explicitly, e.g. in the important link between marketing and R&D (Rothwell, et al., 1974), through frameworks for joint decision making (Kaul, et al., 1995) and barriers in cooperation between R&D and marketing (Griffin, et al., 1996). These related studies are strong indications that business function cooperation is important creating product architecture as well. Nevertheless, the causes in cooperation will be mainly based on information from interviews and documents at Philips.

The lack of cooperation has multiple causes. In many cases departments are not accustomed to cooperating when a new product architecture is created, i.e. there is little to no culture of cooperation. During interviews several causes for this emerged. They were categorized into two groups. First there is often an asynchronicity between departments operating at the start (e.g. product management / R&D) and at the end (e.g. sales/marketing) of the New Product Development process. At the time market feedback is passed back to product management, the latter are already planning the products for the next five to ten years. Therefore feedback about existing architectures does not generate direct results for either of the business functions and cooperation goes straight to the bottom of the priority list. A limited mutual understanding can be the second cause for a limited culture of cooperation, since people come from different disciplines. Overstated, a marketeer thinks in terms of market share whilst an engineer in terms of kilowatt. This was identified during interviews but also turned out to be one of the major aspects in the evaluation of the Architecture Improvement Method: *"the differences in paradigms between departments were very remarkable"* (Teuns, 2005 p. 97).

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[1] e.g. (Morris, et al., 1993) (Baldwin, et al., 1997) (Sanchez, 2000) (Pil, et al., 2006) (Fixon, 2007)

Another reason why business functions do not cooperate in creating product architecture, is because they do not see the relevance of it, i.e. its influence on company performance. Increasing mutual understanding could help to qualitatively show the effects of architectural decisions, which was already aimed for in the Architecture Improvement Method. However, architectural relevance is mainly not seen because financial outcomes of architectural decisions are usually unknown. Outcomes of architectural decisions should be known in terms of costs, potential market gains, etc, for people to see the impact on the company. One respondent stated the following: *"It helps if you could show the financial consequences to people who are not in engineering or are not convinced by engineers"*

An increase in financial insight would also help to persuade BU management in allocating resources to product architecture. This is often needed because business functions can have conflicting interests when architectural decisions need to be made. For instance, if marketing requires interfaces for extra product variants, R&D and production might suffer extra costs. Only BU management can repeal these conflicting financial interests between business functions, since they can decide to invest or alter targets. Therefore they too need to be convinced of the relevance of product architecture. Insight in the financial effects of architectural decisions can aid in this. This point was highly stressed in the Architecture Improvement Method evaluation (Teuns, 2005). Statements in unprocessed data of five cases include the *"need to convince management with clear results and key performance indicators"* in three cases and the *"need for hard facts/quantification"* in two cases. All five cases indicate they would like *"participation of management/decision makers"*. Furthermore, the report indicated to *"convince management of an organisation"* as a future goal (Teuns, 2005 p. 97).

Although everybody would benefit from knowing financial outcomes on all business functions, cooperation always consume a rather large amount of time and effort through meetings and discussion. Therefore, any method will be of low value if the time burden to apply it is too high. For instance, a questionnaire in the Architectural Improvement Method was assessed rather low by the respondents because it took too long to complete (in some cases 9 or 20 hours). Therefore, methods need to be practical.

Insight in financial effects

Knowing financial outcomes of product architectures, would not only help to show the relevance of the product architecture, but it would also help to see which particular decisions is best. Therefore, this knowledge would also have a direct effect on the joint creation of product architecture. As indicated above, the need for quantification appeared in both interviews and the cases of the

Architecture Improvement Method. In literature, no studies are known that examine the relation between financial insight of business functions and the way they create product architectures. However, literature shows the relevance of this area, since many investigate the effects of product architecture on the firm. For instance, some studies take a qualitative approach (Pil, et al., 2006) (De Weerd-Nederhof, et al., 2007) whilst others seek statistical evidence for these effects (Lau Antonio, et al., 2007). Furthermore, multiple studies indentify cost and time as two effects of product architecture, e.g. (Fixon, 2007) (Boer, et al., 1999). However, there is still no general consensus on the main effects that architectural decisions have on a company and there is still a need for methods with *"economic justification"* (Jiao, et al., 2007).

Despite the need and academic attention, it remains a challenges to make an accurate quantification. Two main reasons are appointed for this. First, architectural decisions need to be made in the early design phase, when there is no detailed design available. This make it hard to determine cost effects on for instance production, materials and assembly. Secondly, quantification is difficult because future developments in market and technology are uncertain. So not only are the cost effects unknown, but the future market and technological demands are uncertain as well! Because of this uncertainty, it is hard to make adequate predictions about new market and technologies, let alone to translate this into quantified data such as market forecasts. One respondent stated about market forecasting that *"because of the uncertainty of the future [the product managers] struggle to give it a shot at all"*.

Since it remains a challenge to quantify product architectures accurately , not many product architectures are financially evaluated in practice. Furthermore, there often little time available to make an extensive analysis. Therefore only a practical method will be useful. After all it will provide financial insight in product architectures that otherwise would not be evaluated at all. Accordingly, a quantification should be sophisticated enough to accurately represent reality, but it should not be too complex to lose its ease of use.

Practical use

Despite the relevance of quantification in literature, the author could not find readily available methods that quantify product architectures fast and easy. Some methods require many input parameters, which makes them extensive in time and input. Others have a rather specialized field of applications since they are either mathematically complex or focus on the technical aspects of product architecture. These issues are not very practical when dealing with a multidisciplinary team and with high uncertainty about the input data. These issues about known methods are discussed more extensively in Chapter 4.

Requirements: Answering Q1

At this phase, it is possible to answer central question 1. The question is repeated below.

Q1: What are the requirements for the method?

In the problem analysis, practical quantification is assumed to have two effects on the creation of product architecture:

(1) It can increase the insight in financial effects

(2) It can increase the cooperation between business functions

However, these effects are hypotheses: their effect is assumed, but scientific evidence lacks. Since testing these hypotheses requires many individual studies, it is impossible to accept or reject them in this study. However, an indication of these effects can be obtained. After all, it is possible to ask users about the financial insight they perceive and their willingness to cooperate on product architecture in the future.

Requirements for the method will now follow, answering central question 1.

1. The method should increase the willingness of participants to cooperate in creating product architecture
2. The method should increase the financial insight according to participants
3. The method should be practical

Chapter 4 Related work

Introduction

The past chapter showed the relevance of a quantitative method which is practical. In addition, three requirements for a quantitative method were stipulated. The current chapter investigates related work in the academic literature and at Philips AppTech to answer central question 2. This question is repeated below.

Q2: What is the current state of the art in valuating decisions in product architecture?

This chapter is split into two parts. First, known approaches to value product architecture are discussed. After all, a method which meets the requirements could already exist. However, as will be shown, this does not turn out to be the case and a method needs to be constructed. It is therefore needed to investigate the fundamentals of valuation.

Accordingly, a second part of this chapter discusses theories to valuate investments. This includes the Net Present Value (NPV), Decision Tree Analysis (DTA) and Real Option Valuation (ROV). The chapter not only explains how the theories work, but also what they assume and lack. Element of these valuation theories are adopted to create new method later on in this thesis. The chapter ends with a conclusion that answers central question 2.

Known approaches

The current section discusses the known approaches in literature and at Philips AppTech. The logics are stated in Exhibit 7.

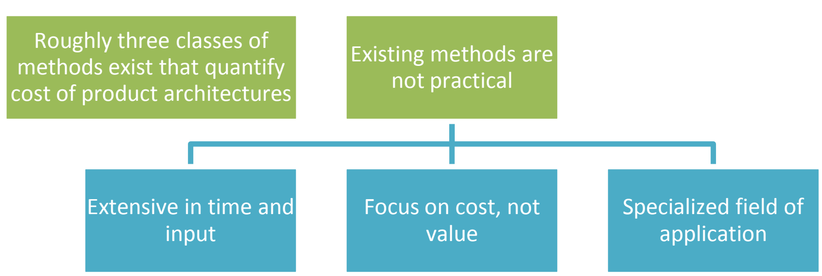

Exhibit 7 – Logics of the known approaches in product architecture quantification

A classification of methods

As stated in Chapter 3,many studies try to investigate the (financial) effects of product architecture on a firm using for instance qualitative or statistical methodologies, such as (Pil, et al., 2006) (De Weerd-Nederhof, et al., 2007) (Lau Antonio, et al., 2007) (Fixon, 2007), (Boer, et al., 1999). However, these studies are interested in architectural effects but do quantify individual architectures.

A separate class of studies does try to quantify product architectures and mainly focuses on cost. (Fixon, 2006) and (Layer, et al., 2002) classify these cost estimation methods in a rather similar way:

1. **Parametric models** that use historical data of cost drivers and apply it to a new design
2. **Analogous models** that try to find similarities between old designs and a new one and
3. **Analytical models** that model the cost structure of a product.

Existing methods are not practical

Despite the attention in literature, many of these existing models are not practical. For instance, they often require too much input data that is either uncertain or unknown. This is especially the case for parametric and analogous models. After all, both of them require extensive historical data sets. For instance, parametric studies include finding statistical correlations between modularity and cost. These relations are used to estimate the cost of future products. However, the conclusions of these models are not always conclusive and they require vast amounts of historical data, e.g. (Guo, et al., 2007).

Other studies include evaluating product architectures using commonality indices (Thevenot, et al., 2007) or modularity indices (Mikkola, et al., 2003) but these specific studies lack financial backing.

Some rather analytical models use Activity Based Costing (ABC) and/or Monte Carlo simulation techniques to estimate the cost impact of an architecture (Siddique, et al., 2001) (Suh, et al., 2007). However ABC methods are usually time consuming. Furthermore, these studies focus on cost only and disregard the extra revenues that a specific product architecture might generate.

Note that not all studies originate from business or accountancy disciplines: many quantification methods come from the field of engineering. Due to the attention from engineering, cost estimation methods vary in technical focus. Strongly technically oriented methods include optimizing technical product variables (Dai, et al., 2007) (Fujita, et al., 2003) or linking cost estimation algorithms with Computer Aided Design (CAD) packages to generate cost optimal designs (Suh, et al., 2007). Although these methods may be very useful in product design, they are often less suitable to jointly make strategic architectural decisions because of their specialized field of application.

Philips AppTech also uses several methods to quantify design decision on beforehand. The so called Men, Machine & Material (MMM) model is frequently used in order to obtain insight and to minimize the integral production cost of a product. The model is a simple ABC method which is fast and easy to use. However, it is not intended to evaluate strategic architectural decisions nor does it include potential value: it only determines cost. Diversity Based Costing is another method known to Philips AppTech. It determines the cost on the entire supply chain due to the product diversity that is offered. The model does include effects on various business functions and has been applied successfully in a case. However, the model does require a lot of input data and only evaluates cost, not value. Consultants at Philips AppTech often use the delta model to quickly quantify the financial impact of architectural decisions. It is an analytical model that includes the extra costs and revenues of adding functionality to a product architecture. Although the method can be applied fast, it does not account for uncertainty, which is a significant characteristic of architectural decisions in reality (see Chapter 3).

More recently option theory from the financial market gained attention from academics because of its ability to account for uncertainty, managerial choice and value of investments. Furthermore the Black-Scholes formula (Black, et al., 1973) enables practitioners to calculate value in a fast and easy way. Applied to real investments, option theory is known as real option theory. This theory will be discussed more thoroughly later in this chapter. Real option theory is used in many areas related to R&D. For instance, benefits of modular projects in general can be shown using real option theory (Rodrigues, et al., 2007). The Black-Scholes formula is also used to make go/no go decisions in the product development process (Lint, et al., 2001). Some studies in product architecture use real option theory as well. For instance, it is used to identify cost optimal modules in a product, based on an extensive design structure matrix (Sharman, et al., 2007). The real options concept is used to select the most valuable product platform from alternatives by evaluating the product variants that they can enable (Gonzalez-Zugasti, et al., 2001). However, these methodologies on product architecture are mainly suitable for a specialized field of application, are rather extensive in time and require many input parameters. They are less suitable as a fast, general instrument in assessing product architecture. Real options has also been used in a variety of case studies in building projects (Gil, 2007). Based on these results, types of active and passive safeguarding are mapped on the axis of uncertainty and modularity. Although this is an applicable framework for decision making, the data quantification itself is done by the researcher. It does not provide a practical way for practitioners to quantify these decisions themselves.

Conclusion about the known approaches

Concluding, many studies investigate financial effects on the company related to product architecture. Methods that quantify product architecture usually focus on cost, have a specialized field of application and are extensive in time and input requirements. This makes them less suitable as a fast, general way to quantify product architectures. Therefore their practical applicability is often limited and they are not used in practice. This shortcoming seems to be shared by some researchers who state that *"today the methods for platform product development are not practical and future results can be obtained with an integral methodology using a practical design representation linked to an optimization methodology. Such methodology should link the most important costs, the economic savings and the design choices."* (Jose, et al., 2005) Therefore, I conclude that existing methods are not practical.

Since existing frameworks do not meet the requirements, a new method needs to be constructed. Since the method should quantify financial effects, it is essential to base this on proper valuation theory. Therefore the next section of this chapter discusses different valuation theories and –highly important– stipulates their assumptions and shortcomings.

Valuation theory

Before discussing valuation theories, the reader should know the concept of valuation. Stated simply, and in essence it is simple, valuation is estimating what something is worth. Usually this is expressed in money. However, estimating this worth is not always clear. After all, people have different views of the value of assets. For instance, a photograph of his girlfriend might be worth a lot to the author, whilst it might be a worthless piece of paper to another (that depends on several factors). Likewise, a company can be valued as well, i.e. one can estimate it's worth. However, the question arises what it's worth to whom? Different people and different circumstances might lead to different valuations. Therefore in finance valuation refers to the estimation of the market value, i.e. what the company would be worth if it is traded on the market. Market value is defined as follows (International Valuation Standards Committee, 2003):

"Market Value is the estimated amount for which a property should exchange on the date of valuation between a willing buyer and a willing seller in an arms-length transaction after proper marketing wherein the parties had each acted knowledgeably, prudently, and without compulsion"

Concluding, the valuation of a company, a house or any other asset is estimating what it's worth on the market. This is highly dependent on the profitability of the individual activities of a company. Therefore, when companies have to choose between investing in alternative activities, it will choose the one that increases the market value of the company the most. Accordingly investments themselves need to be valuated. This is essentially what the method should do with different product architectures: it should estimate which product architecture has the highest market value. Techniques to do so are discussed in the current section.

Valuation of investments is typically done by a Net Present Value (hereafter NPV) calculation. However, an NPV calculation has some shortcomings when investments are uncertain or staged. As one will see further in the thesis, this definitely is the case in product architecture. Therefore recent developments in the area of decision tree analysis and real option theory try to account for these shortcomings. Elements of these theories will be used to create a new method later on in this thesis. Therefore, these theories, their assumptions and shortcomings will be discussed in the following section.

Net Present Value

The Net Present Value (NPV) valuation is the most commonly used technique to value investments. It determines the value that a project has to a firm, expressed in money in the present. The underlying principle is that using *money costs money each year*. Thus in order for a project to add any value to a company it should at least generate this cost of money, i.e. the discount rate. Appendix A discusses the mechanisms of NPV and its underlying assumptions.

The pitfalls in Net Present Value valuation

When investments are valued using an NPV calculation, there are some drawbacks. These are discussed now. First an NPV does not account for uncertainty, but assumes fixed cash flows. However in reality there is often uncertainty about these cash flows. For instance, assumptions about cash flows may be more realistic as a range rather than a fixed value. This is illustrated in Exhibit 8. The cash flow in year 1 can vary between €20 and €70. However, the uncertainty can be complex because of the non-linear nature of reality. For instance, cash flows can have peculiarly shaped probability distributions or be correlated in reality.

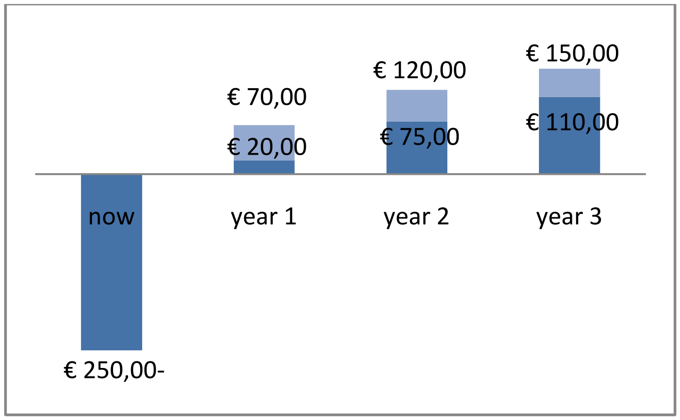

Exhibit 8 - Cash flow diagram of a fictive project with ranged cash flows

Managers try to compensate for this uncertainty in several way. First, they add extremely high risk premiums on top of the discount rate. Because this does not reflect a market equivalent cost of money of a project with similar risk, these project are usually highly undervalued (Slater, et al., 1998 p. 449). Secondly, managers assume several scenarios and determine the Net Present Value for each scenario to deal with uncertainty. For instance, an optimistic, a pessimistic and a base scenario is determined. These scenarios are useful as a sanity check, by evaluating extremes. It is also common practice at Philips AppTech. However these scenarios provide a somewhat simplified picture, since they barely resemble the wide range of possible scenarios in reality. Furthermore, the base case NPV does not always have to equal the average NPV of the real uncertainty. However, in practice people do (implicitly) assume this by calculating with the base case[2]. Therefore, the base case can be either too pessimistic or too optimistic if it is compared with the real uncertainty. This is illustrated in Exhibit 9. Although it is virtually impossible to know the real uncertainty, better results can be obtained if the real uncertainty is approximated with a modelled uncertainty as realistically as possible.

[2] This is true if decision makers are risk neutral. Of course in reality they are almost never and a utility function would be appropriate. However the point here is that 3 scenarios do not always represent real uncertainty.

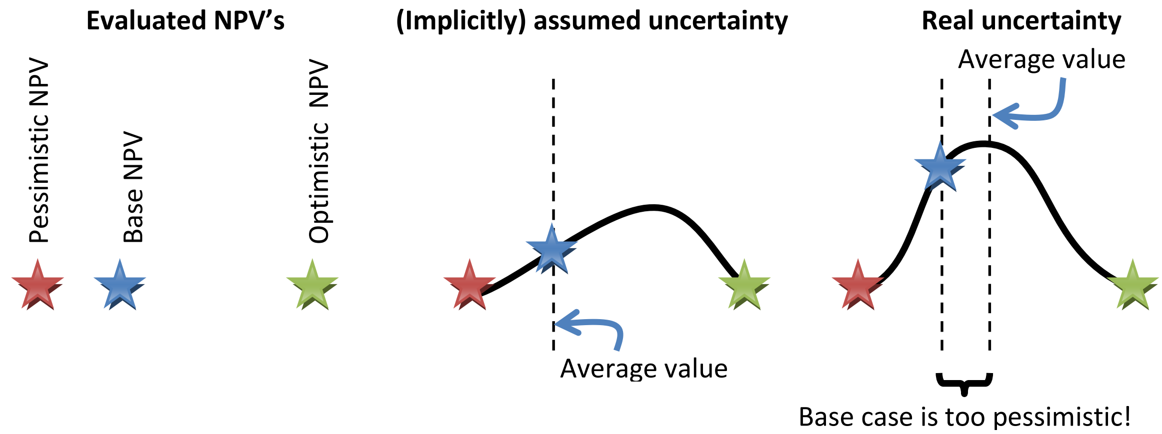

Exhibit 9 – A base case NPV can be either too optimistic or pessimistic if people assume it to be the average value

A second pitfall about the NPV is the exclusion of future choice. An NPV assumes a predetermined path of an investment. Cash flows of all future years are determined according to a fixed plan. However, in reality many investments are not predetermined, but staged. They are split into several milestones and at every stage managerial choices can be made, like continuing the project, cancelling it, postponing it, etc. This is especially the case when the outcomes of investments are uncertain. For instance, R&D projects may start with a technical feasibility study, followed by a market feasibility study, a detailed technical design, a small market test and finally a big market launch. At each of these stages managers have a choice to continue to the next stage or not, based on the knowledge that is available at that moment in time. Thus each stage actually creates several options for a company and the company will chose the most profitable path based on the information that is available at that point in time. For instance, if a project turns out to be unsuccessful, a project will be cancelled or postponed. Although the company will then suffer some losses, these losses are usually much lower than when the project would be continued. Therefore, staging investments is in fact a way of reducing risk (Peter Boer, 1998). Since a traditional NPV does not model these stages and future choices, this risk reduction is not taken into account. Accordingly the NPV tends to be too conservative, i.e. it under-valuates these uncertain and staged projects as well.

Decision tree analysis

As stated above, an NPV does not valuate investments with high uncertainty very well. Furthermore, they also do not take managerial choice into account. Decision Tree Analysis (DTA) is able to model this, by making a tree of uncertainty nodes and decision nodes. The mechanism of DTA will now be discussed in the thesis, since it is an important prerequisite for understanding the method in Chapter 5.

The mechanisms of Decision Tree Analysis

A decision tree analysis (DTA) can be used to deal with uncertainty and managerial choice. It models multiple possible paths that an invest can take through succeeding nodes. These nodes can either represent uncertainty (usually depicted with a circle) or can model a decision (depicted with a square). Consequently, they are valued differently as illustrated in Exhibit 10.

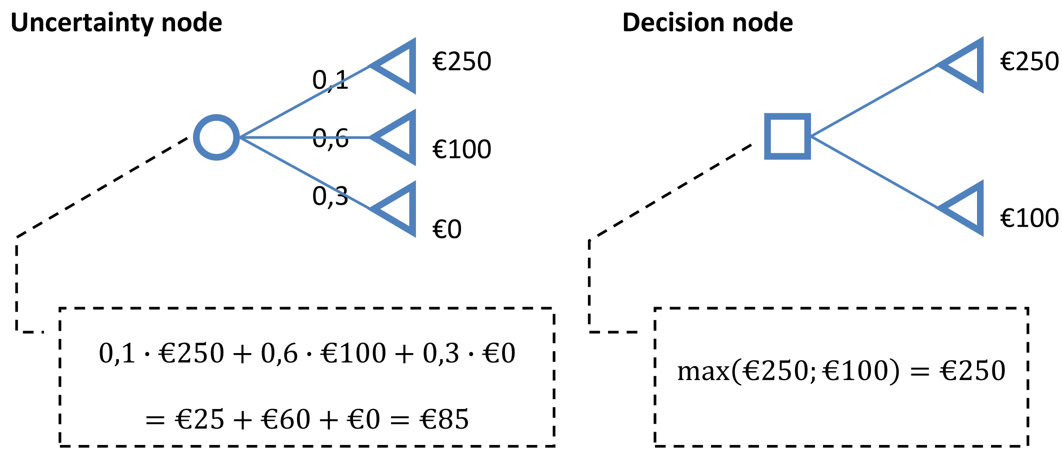

Exhibit 10 - Valuation of decision tree nodes

Uncertainty nodes are divided into several probabilities whose sum is equal to 1 (Equation 1). Since uncertainty is usually not controllable by a company, the node is valuated as the expected value of the branches according to Equation 2.

$$\sum_i p_i = 1$$

Equation 1

$$NV_{uncertainty} = \sum_i p_i V_i$$

Equation 2

$$NV_{choice} = \max_i V_i$$

Equation 3

NV: node value

p_i: probability of branch i

V_i: value of branch i

Decisions however are fully controlled by a company. Since companies seek to maximize profit, it is expected that a manager will choose for the investment branch with the highest value. Therefore a decision node's value is the maximum of its branches as stated in Equation 3.

Staged investments can be modelled by constructing a decision tree. The following example will be used. A company has a choice to develop a new technology for €100. The development will take a year and has a 50% chance to be successful. If this is not the case, extra research can be done for €65 at a 70% chance of success. If the technology is available, the company has the choice to launch the product at some marketing expenses: €100 for one year of marketing and €150 for two years. Based on market research, there are three possible market responses: good, normal or bad. The revenues of each response are stated at the end nodes. For simplicity, there are only two years of sales possible before the technology becomes obsolete. The decision tree is depicted in Exhibit 11.

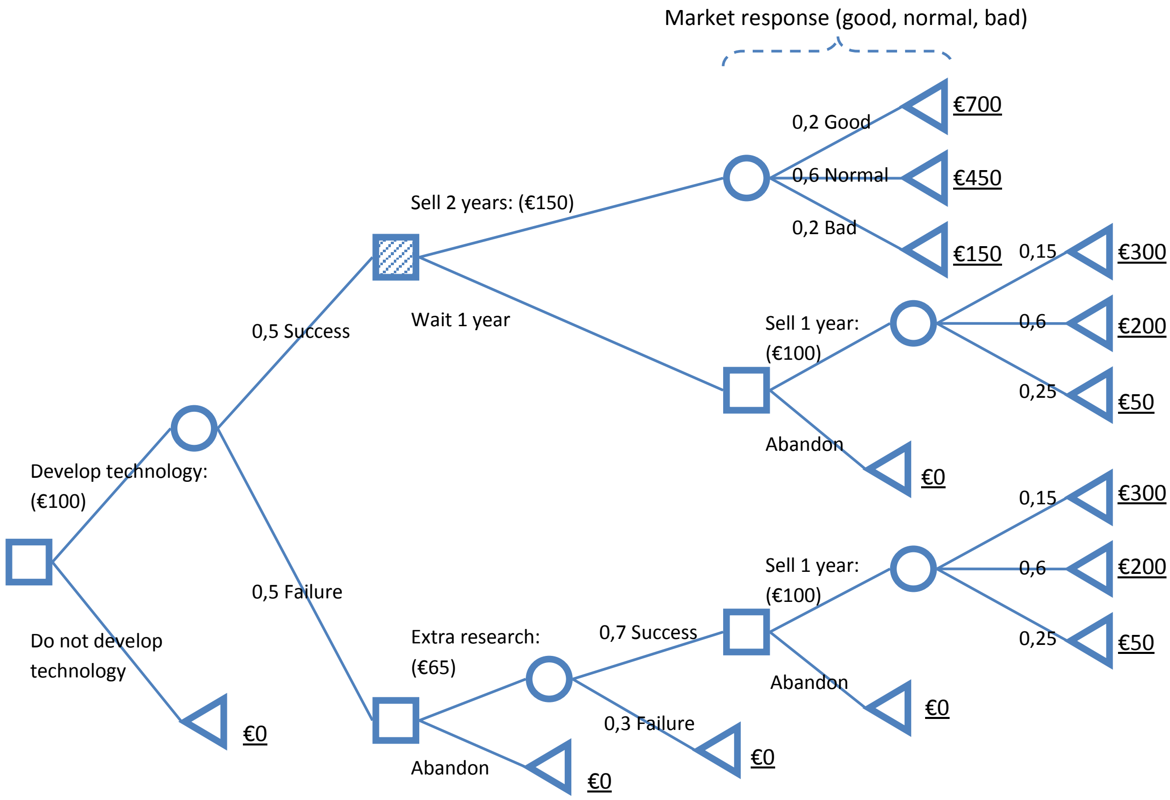

Exhibit 11 - Decision tree of a fictive investment

Using the valuation rules of Equation 2 and Equation 3, the nodes can be rolled backwards to the initial decision of developing the technology. Each rollback leads to an equivalent, simplified tree. Some intermediate steps in the rollback process of the highlighted decision node are depicted in Exhibit 12.

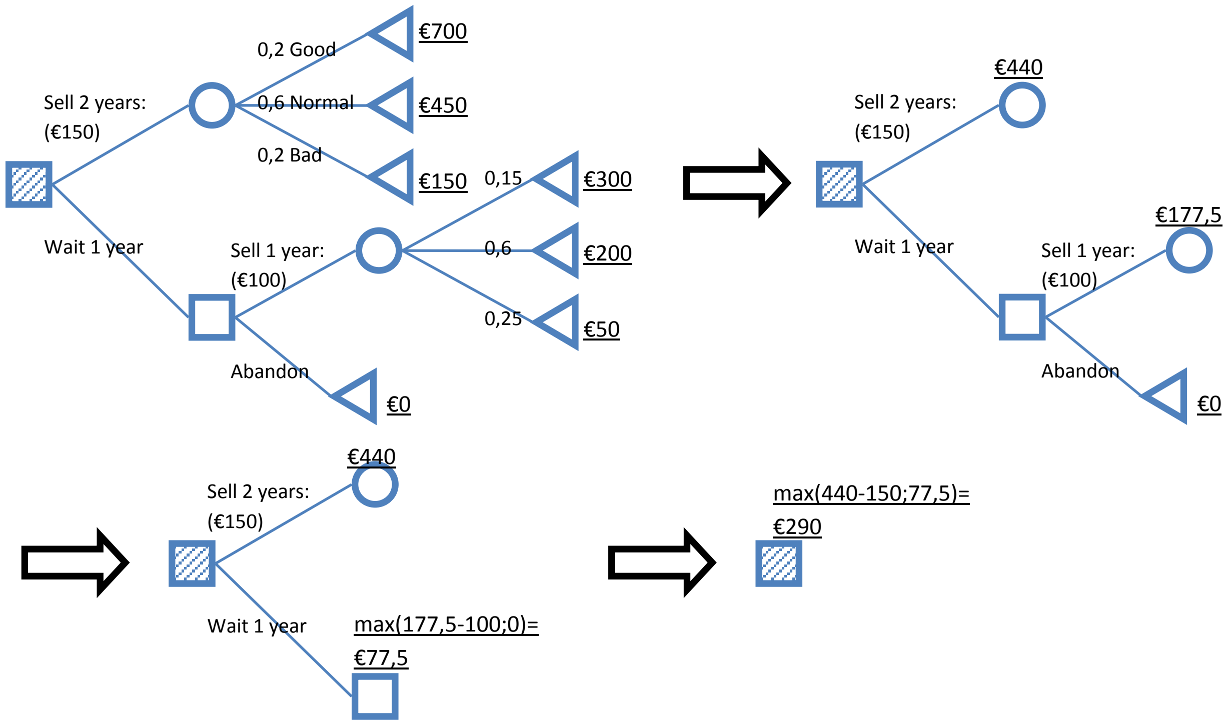

Exhibit 12 - Intermediate steps in the rollback of a part of the decision tree

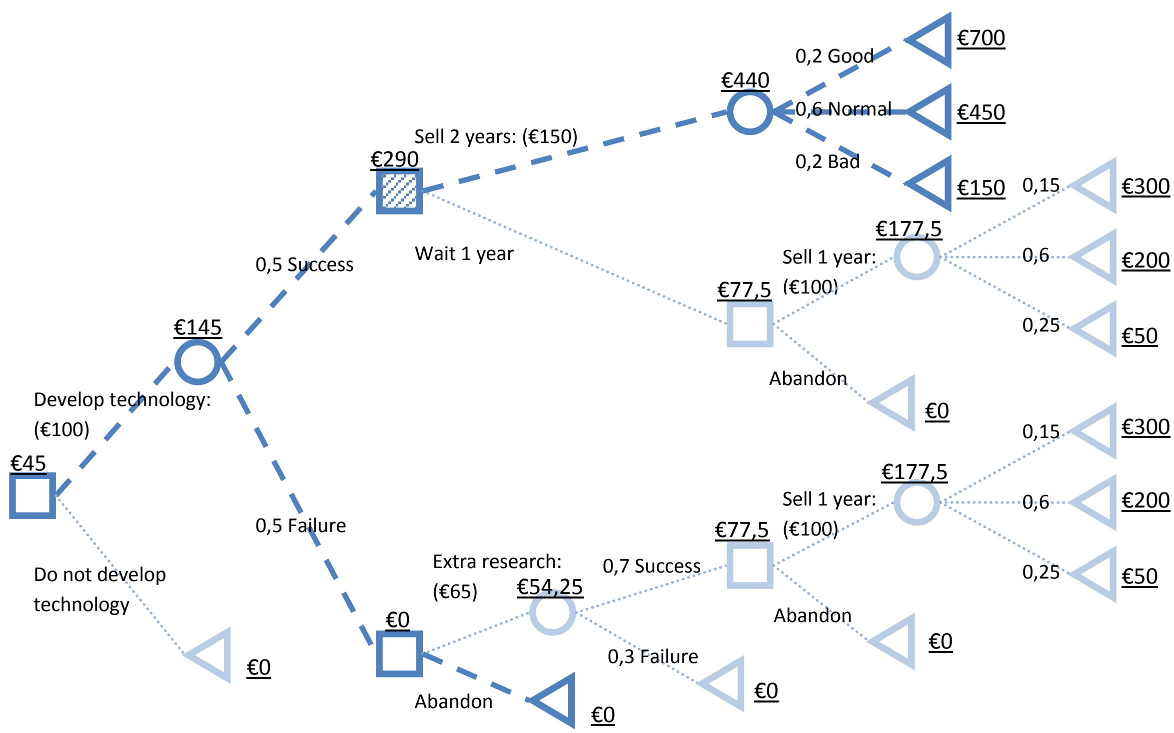

Exhibit 13 - Evaluated decision tree

The valuation of the entire project can be found in Exhibit 13. The optimal path with optimal decisions is highlighted. The value maximizing strategy is to develop the technology, since this is expected to add €45 of value to the company. If the development is a success, the technology should be sold for 2 years. However, if the developing fails, the project should be abandoned.

The pitfalls in Decision Tree Analysis

Several problems arise in using decision tree analysis. First, the tree usually becomes very complex very fast, since it grows exponentially. This is not noticeable in the example problem of Exhibit 13, since is it greatly simplified. However in reality many more uncertainties and choices exist. This makes the decision tree very large. A decision tree for a relatively simple problem is depicted in Exhibit 14. This tree already counts 94 different end nodes.

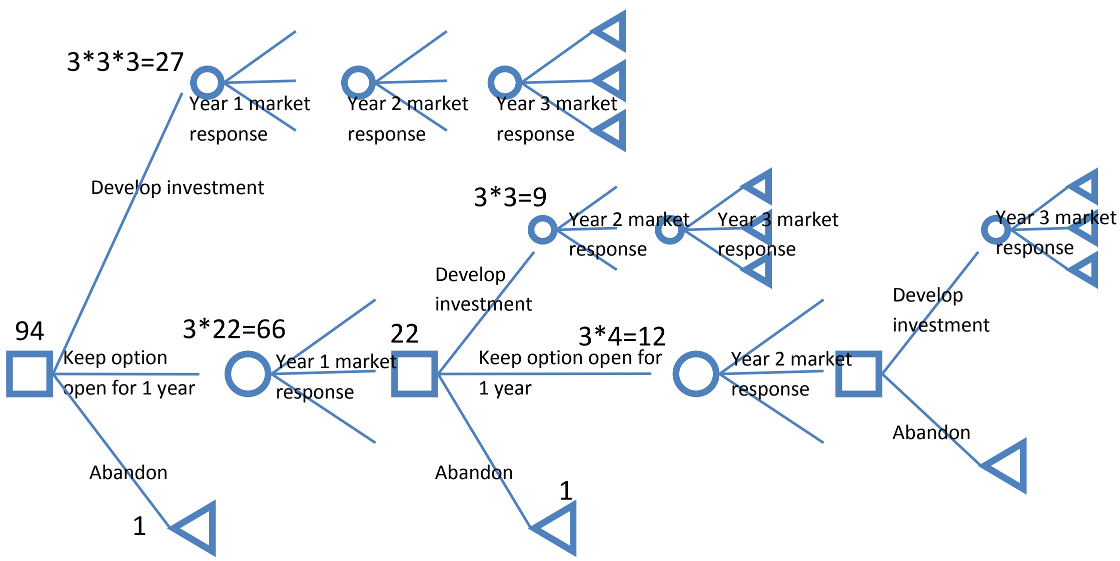

Exhibit 14 - Example of a more complex decision tree

Due to the complexity, the structure of the investment becomes difficult to understand since the tree gets hard to visualize. Furthermore, enormous amounts of data are required for the tree. After all, each branch leads to a different investment path for which all probabilities and end node values need to be determined. For instance, Exhibit 14 counts 208 input variables[3]. Often this amount of data is hard to estimate.

The second drawback of a decision tree analysis is the problem of discounting the end node values. As sales and costs can occur in the future, they need to be discounted to a present value in order to account for the cost of money, like in an NPV. For clarity this was disregarded in the examples. In

[3] 94 end nodes and 114 probability nodes make 208 input variables

practice the WACC[4] is often used as discount rate (Borison, 2005). Nevertheless, the use of this discount rate is in reality incorrect. Recall that the discount rate should equal the market equivalent cost of money of a project with similar risk and profit characteristics. After all, projects differ in their probability and profit potential and accordingly investors will require a different return on investment. The tricky part in a decision tree is the numerous paths that the investment may take. Since each investment path has different probabilities and expected profits, each path also has different risk characteristics. Consequently each path requires a different market equivalent cost of money. This means that for every investment path a project with similar risk characteristics should be found to determine a market equivalent cost of money. Only this will lead to a really correct valuation of the decision tree. However in practice this is not realistic. It is already uncommon to determine the market equivalent cost of money of a single project since it costs a lot of effort and it is not always possible. This is one of the reasons why companies use a general discount rate like the WACC. Thus it would be an insane task to determine the different costs of money for every path of a decision tree. Instead, the WACC is often used and the error is taken for granted.

Concluding, a decision tree can be used to model investments with uncertainty and choice. However, a decision tree becomes complex very fast and is not really market equivalent since the use of a single discount rate is incorrect. Real option theory is a new approach to deal with these shortcomings.

Real option theory

The term 'real' option theory was first used by (Myers, 1977) where real investments of companies are valued using option pricing theory from the financial market. Real option theory tries to fill the shortcomings of NPV and DTA. *"From the NPV approach, it borrows the idea that we must find a comparable (perfectly correlated) security to correctly evaluate risk, and from the DTA approach it uses decision nodes (not rigid event nodes) to model flexibility."* (Copeland, et al., 1994). Thus the problems of both valuation theories seem to disappear. It both tackles NPV's shortcoming of not modelling uncertainty and choice and DTA's lack of a market equivalent cost of money. Although this thesis is not meant to explain option theory, the basics of option theory need to be discussed in order to understand the applicability to real investments. Especially the basic assumptions of option theory, called no arbitrage and the Geometric Brownian Motion (hereafter GBM), need to be understood fully since it forms the basis of the real option theory valuation. Many of the approaches on real option theory lack

[4] Weighted Average Cost of Capital. This is introduced in Appendix A: The mechanisms of Net Present Value

this discussion and there are contradicting views on the validity using these assumptions on real investments (Borison, 2005). Therefore, the two basic assumptions of option will be discussed briefly. Appendix B explains the basics of option theory and the assumptions into detail.

No Arbitrage: the assumption of a complete free market

Option theory uses a completely different assumption than NPV and DTA. Instead of a cost of money, the price is determined by the existence of arbitrage. Arbitrage is a construction that can be made in the stock market that requires no investment but makes a guaranteed profit. However, this is only possible if the price of an option does not reach a specific price. This is the price that is determined by option theory. Since everybody would like to have a free guaranteed profit, the price of an option converges very fast to this point where no free profit (arbitrage) can be made. This is because shares and options can be traded on a complete free market with many buyers and sellers. Thus, the price from option theory is only correct if there is a market with many buyers and sellers that in which it is possible to buy shares and underlying options.

The Geometric Brownian Motion (GBM): the assumption of stock like price behaviour

In order to determine the non arbitrage price of an option, it is necessary to know the prices of stock in the future. Therefore, the prices are often modelled with a Geometric Brownian Motion that is based on historical data of the stock price. This is the second assumption in option theory. In words this equation is stated below.

$$Price\ tomorrow = Price\ today + Part\ of\ the\ price\ today + A\ random\ fluctuation$$

The price in the future is thus dependent of the current price. Often the start price of the stock price is denoted as S. A part of this price will be added to get tomorrows price. This part is called the drift μ and is based on historical data. Furthermore, the price gets a random fluctuation up or down, which is normally distributed. The size of the fluctuation is based on the volatility σ, which is again a historical parameter. The equation can be repeated to know possible prices further ahead in the future. Since the fluctuation is random, the price can behave in multiple ways and many price paths are possible.

The GBM is illustrated in Exhibit 15 with an example. In this figure, three example paths of a GBM are plotted for a stock with current price S of €300, a volatility σ of 42% and no drift μ. Each path starts at the current price $S = 300$ and for each day[5], it fluctuates randomly with a normal distribution. The

[5] For illustrative purposes a day was chosen as time step. Any other time step can be used as well.

equation is repeated for three years. If many price paths are determined, one can see that the values are lognormal distributed. This is one of the important characteristics of a GBM and can also be seen in the figure.

Concluding, option theory is correct if the underlying asset behaves like a GBM. This means that prices alter every time step with a drift and with a random, normally distributed, fluctuation. As a result prices at any point of time are distributed lognormal.

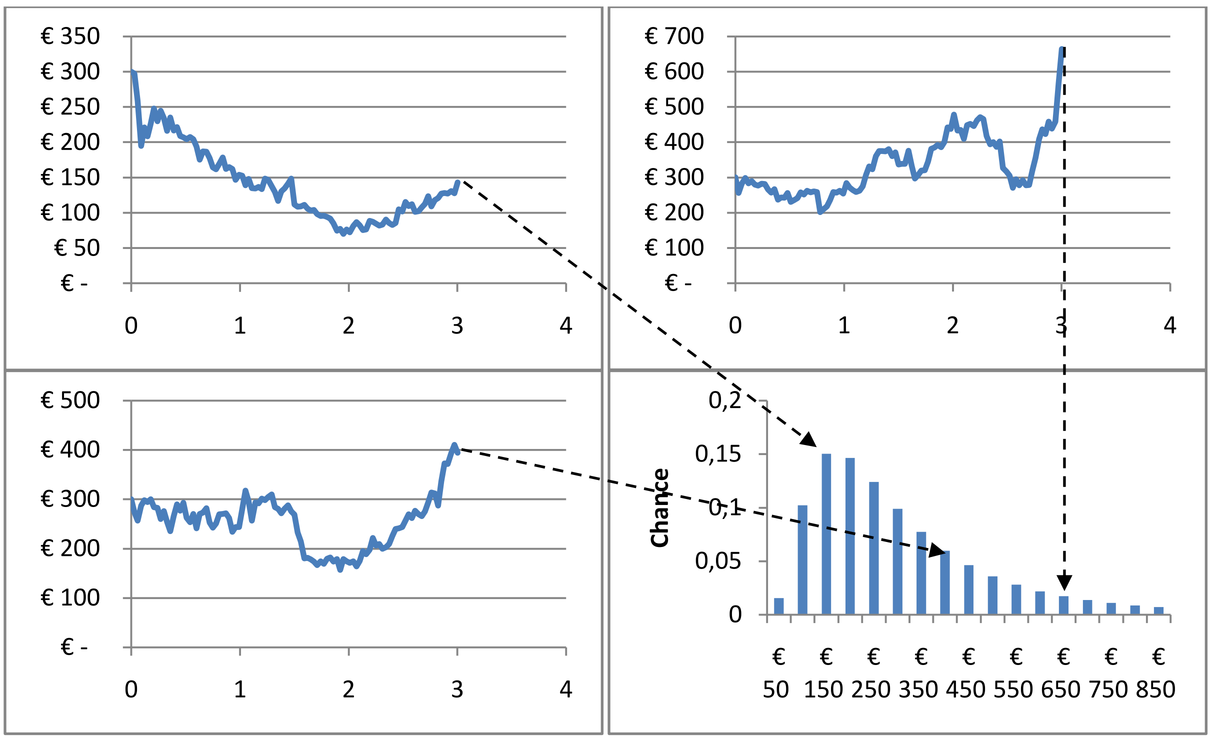

Exhibit 15 – Three samples of a Geometric Brownian Motion with $S = 300$ and the lognormal probability distribution of the value after 3 years[6]

Option theory applied to real investments

Option theory can be mapped to real investments using the following analogy. The Net Present Value of an investment equals the current stock price S. This value of the investment may fluctuate over time with a volatility σ, just like the stock price. In this case this is due to risks in the investment. Once a company does decide to launch the investment, the costs X (also denoted as K) are incurred. Naturally,

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[6] The simulation run for $i = 1000$ times to calculate stock prices after three years $S_{i,t=3}$. The natural logarithm of these prices were taken $X_i = \ln(S_{i,t=3})$. For the figure a lognormal distribution is taken with average $\mu_{lognormdist} = average(X)$ and standard deviation $\sigma_{lognormdist} = stdev(X)$. This approximates a histogram of the simulation.

this decision will only be made if the investment value outweighs the costs (so if $S - X > 0$). Furthermore, the decision to invest can be made up to time t, which equals the expiration time of an option. The future profit can be discounted with the risk free rate r. Exhibit 16 (Luehrman, 1998) illustrates the analogy.

Exhibit 16 - Mapping an Investment Opportunity onto a Call Option. Adopted from (Luehrman, 1998)

Once a real investment is mapped into an option with the analogy above, the investment value can be determined using methods to calculate the value of an option. For instance, some use the Black-Scholes formula (Luehrman, 1998) or a binominal lattice (Copeland, et al., 2004). Monte Carlo techniques can be used as well. Real options theory does not have to involve single investment decisions. Investments with multiple stages can be valuated as compound options as well (Copeland, et al., 1998) (Peter Boer, 2003).

The pitfalls in Real Option Theory

The main problem in using option theory for real investments is the validity of its assumptions. Recall that these are no arbitrage and GBM price behaviour. For financial options, these assumptions hold very well. After all, arbitrage is a leading mechanism in the financial markets. Furthermore, price behaviour can be modelled quite accurately with a GBM based on historical data. However, for real investments, these assumptions are not always that valid and should be evaluated in each case individually (Borison, 2005). The next section will discuss the validity of the two assumptions in real investments and especially concerning product architecture investments. The applicability to investments in product architecture will also be discussed in this section, to avoid fragmentation of theory throughout the thesis.

The no arbitrage assumption in real investments

First, let's discuss the assumption of no arbitrage. After all, the option theory uses the assumption that there is a complete free market for the investment. Only then would the value of the real investment be market equivalent. Thus for the assumption to hold it should be possible to buy portions of the product architecture investment on a free market. Furthermore, there should also be many tradable options on the free market to get the opportunity seeking of the arbitrageurs going (who are trying to get a guaranteed free profit). However, in the case of real investments only a single company is deciding to do a single investment. So the outcomes of the investment are not traded in a large, transparent market at all. Let alone do options exist for this investment. Therefore, there is no possibility for arbitrage with a replicating portfolio if the call option deviates from its non arbitrage value. After all it's not possible to buy a portion of the outcomes of the investment, buy some risk free loans, and get money from writing a call. Clearly, arbitraging in real investments is not possible.

There would be a workaround to this situation if we could make an equivalent portfolio of assets that are traded on the financial market and whose expected returns and risk equal the investment in product architecture. For instance, maybe we could find a bunch of loans and stocks that have the same characteristics as the investment in product architecture. Then we could make another assumption: a call option on this equivalent portfolio equals the value of the real option if it would be traded. Although the portfolio would still be far from equivalent, for a gold mine this might be a reasonable approximation. After all, the gold price is probably reasonably correlated to the output (and thus value) of the mine. However for many other investments, especially for product architecture, it would probably be impossible to find an equivalent portfolio. Even if this would be possible, again the assumption will not hold. After all, if the company would decide to sell their investment in product architecture to others, it will probably not be traded on a free market, but traded amongst a few other companies. In that situation, the value of the investment will probably deviate from the non arbitrage value. Recapitulated, the arguments for using the non arbitrage (free market) assumption in real investments are rather weak: (1) it is almost impossible to find an equivalent portfolio and (2) if the investment would be sold it would probably deviate from the non arbitrage value since it would be sold amongst a few buyers.

The GBM assumption in real investments

There is another assumption in option theory which is not valid either for product architecture and thus weakens the arguments to use option theory even further. That is the Geometric Brownian Motion (GBM). Recall that this is the assumed price behaviour in option theory. Let's look at this assumption in case of an investment in product architecture. Say that by altering their product architecture for mass customization, the company might get some extra profit by selling extra product variants in the future. If the company would sell these variants now, they would expect to have an extra profit of $S = 300$. If this option is valued using option theory, this profit should fluctuate according to a GBM, just like in Exhibit 15. However, it is rather unrealistic to assume such a behaviour, since it is not based on any observed real behaviour (why would the mass customization profit behave like a stock in Exhibit 15?). Even if the profit would behave like a GBM, there is no historical data to obtain the right volatility parameter σ for the size of the fluctuation. Concluding, the GBM assumption is wrong on two grounds: (1) real profits are not likely to behave like a GBM and (2) if it would behave like a GBM, there is no historical data to determine the GBM parameters like the volatility σ.

The Market Asset Disclaimer (MAD) to use option theory for real investments

Another often suggested workaround is the Market Asset Disclaimer (MAD). People in favour of the MAD state that the no arbitrage assumption does not hold in real investments but that option theory can be used anyway since it is the best approximation for a market equivalent value. In the MAD, the market price S should be the NPV of a project and the volatility σ is be based on estimates of the project fluctuations, not on historical market data. As discussed, two assumptions of option theory are violated: (1) the no arbitrage principle is not valid and (2) provided that the investment behaves like a GBM, the GBM estimation is not based on market data. However, the MAD argues that these violations are acceptable. They argue that the cost of capital in an NPV also uses the assumption of market completeness and therefore violates the same principle. After all, the cost of capital is determined by finding an equivalent project with similar risk and expected profit. Clearly, this equivalent project does not exist, which makes both option theory and the cost of capital based on the same weak assumption.

It is true that both methods assume market completeness. However, according to the author both do not require it in the same degree. In addition, the assumptions for option theory deviate much more from reality. For instance, take the cost of money in an NPV. Although the value is based on a complete market, it is very likely that buyers in incomplete markets require a somewhat similar cost of money as well. After all, if there are just a few buyers, they still demand a high cost of money for riskier projects. The risk premium might not be the same as in a complete market, but the costs of moneys are likely related. Therefore, the cost of money will probably also function reasonably well in incomplete markets.

Let's compare this with the violations in real option theory. Violation (1) is just a matter of common sense. If both assumptions are crooked, which one represents reality better: an inaccurate cost of money or the assumption of no arbitrage? As stated above, an inaccurate cost of money probably functions reasonably in an incomplete market as well. However, for the non arbitrage principle to hold, a large, transparent market is a necessity. Arbitrage simply does not work in an incomplete market, not even partly. Therefore, I think that it is better to approximate the market equivalent value by estimating the cost of money than to assume no arbitrage. However, there is still is an error in both approaches and it is hard to prove which one is the better approximation.

However, violation (2) makes the MAD even less plausible. After all, real option theory assumes that profit behaves with a GBM. In addition, the stock price S and volatility σ are just based on assumptions and not on historic market data. Of course, an NPV also uses estimations for the costs and revenues. However, for an NPV these estimations do not imply to represent any market data, since that lies in the cost of capital. Real option theory assumes that profit estimations represent the market value S and the market volatility σ as well. As a result, all input data (except for the risk free interest rate) for real option theory are based on subjective estimations. Nothing is based on any market equivalence at all. Clearly there is an error in this.

The conclusion is now just a matter of logics: do you want one source of error which is partly derived from the actual market (as in the cost of capital), or multiple larger sources of error (arbitrage and GBM assumption) fully derived from estimates (as in option theory)? I choose the first and reject the MAD.

Conclusion about the related work: Answering Q2

At this point central question 2 can be answered. This is repeated below and will then be answered.

> Q2: What is the current state of the art in valuating decisions in product architecture?

The above sections shows that many studies investigate financial effects on the company related to product architecture but do not quantify product architectures themselves. Methods that do provide quantification usually focus on cost, have a specialized field of application and are extensive in time and input requirements. Therefore they are less suitable as a fast, general way to quantify product architectures and have limited practical applicability.

Valuation theories do have their pros and cons. An NPV is a practical method but cannot deal with uncertainty and choice very well. A decision tree can do this better, but can be very complex. Furthermore, it is hard to make market equivalent valuations since different investment paths have different risk characteristics. Option theory does make a market equivalent valuation that includes uncertainty and choice. However its applicability to real investments is very case specific and arguable.

Since existing frameworks do not meet the requirements and standard valuation theories cannot be applied directly, a new method needs to be constructed. The method should quantify financial effects and should be based on proper valuation theory.

Chapter 5 Design of the new method

Introduction

The current chapter will answer central question 3. This is repeated below.

Q3: How is the method shaped?

In a 4 month lasting iterative design process, roughly 80 different models were constructed. During the entire process, the model received feedback from consultants at Philips AppTech. This included two specialists on product architecture, two financial modellers and a person specialized in portfolio management. In addition, the model was repeatedly discussed with both university supervisors. Apart from many informal meetings, over 30 hours of discussion was recorded. After 3 months, a nearly final model was applied at 3 cases at third parties which again led to several minor improvements of the method. This process is depicted in Exhibit 17.

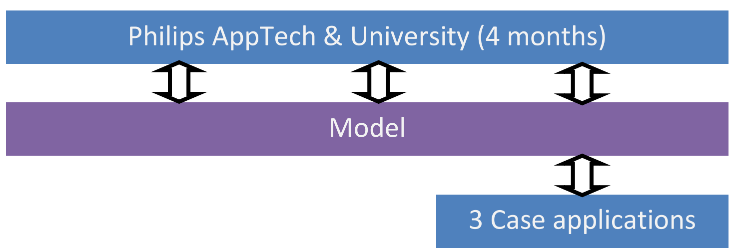


Exhibit 17 - Design process of the method

The chapter is split into the following sections. The evaluation of the method is described first, followed by short case descriptions. Then a section describes how to use the method. Afterwards, four strategic decisions are identified that play a key role in the valuations. Then a section discusses how these four decisions are valuated. The final section shows the implementation of the model in Excel and Visual Basic.

The evaluation of the method

The case applications were aimed to get an impression of the value of the method. Every case consisted of introduction material and two sessions. Data was gathered using interviews, observations during the sessions and questionnaires. The evaluation was set up extensively to enable cases with many participants and is illustrated in Exhibit 18. The researcher had the liberty to deviate from the research strategy if appropriate, in order to prevent the loss of relevant information in smaller cases. The interviews and questionnaires were based on constructs derived from the requirements and included general, explorative, questions about the value of the method. Interviews and sessions were taped and transcribed. Over 8 hours of material was recorded in 3 cases which comprised 5 people in total. More details of the used methodology can be found in Appendix C. The questionnaires and topic lists of the interviews are listed in Appendix D. Transcriptions of the sessions are stated Appendix F. The results of the cases are used to illustrate the method throughout this chapter. Cases are referenced by there abbreviation and the line number of the transcription between square brackets, e.g. [PM 20].

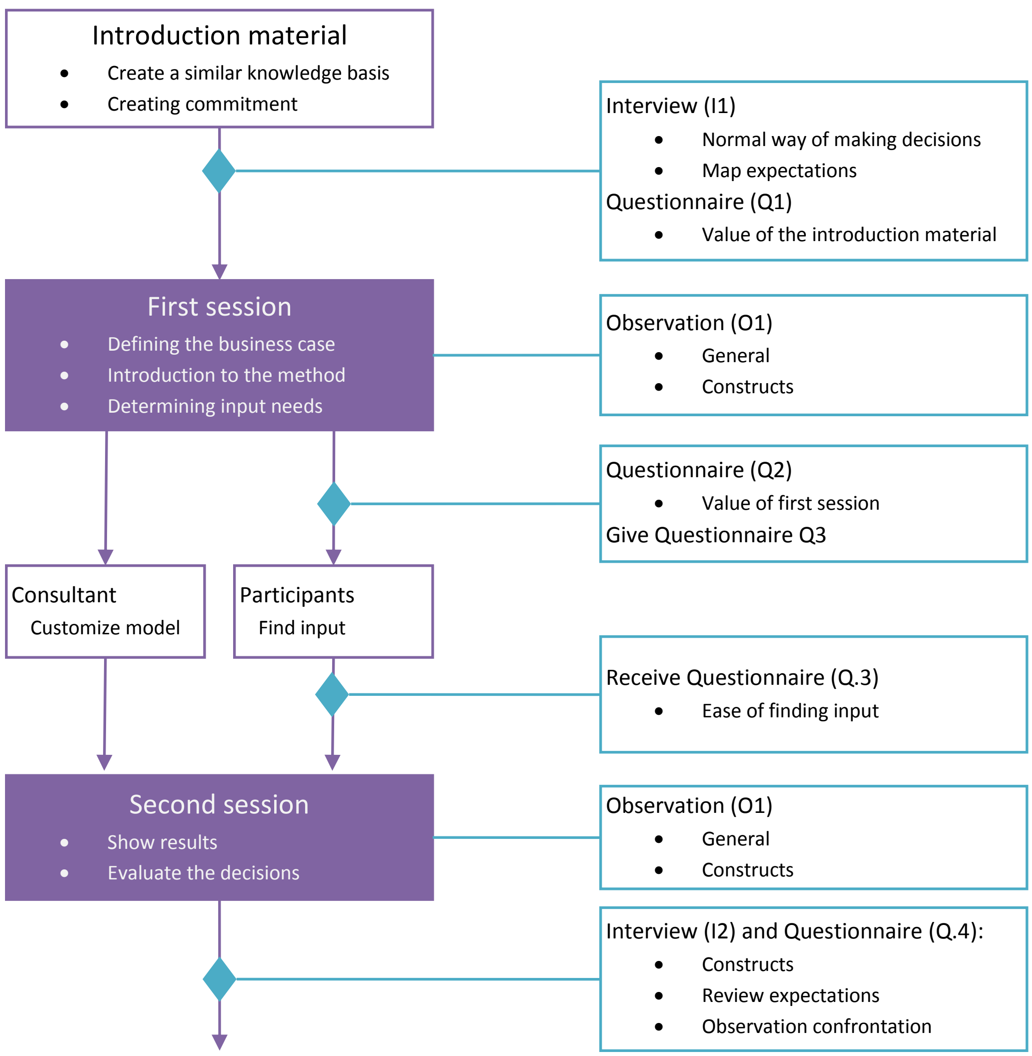


Exhibit 18 – The case evaluation process

Case descriptions

Since this chapter will reference to case responses, a short description about the background of the three cases is given. Because some cases may include confidential elements, names and data of the case might be altered. However it is done in such a way that it does not affect the outcomes of the evaluation. Readers who are interested in additional background information can contact Philips through the contact information given on page 2.

The patient mover (PM case)

The patient mover was a new functionality for a scanner in the medical systems market. This market is characterized by low sales volumes and six to seven figure sales prices. Therefore individual customers are valuable to the company and a great deal of effort is made to offer these customers the functionality they want. Products often require long maintenance contracts and lifecycles are quite long: the time from design to the last service can take up to 20 years. Therefore architectural decisions have a long lasting impact on the company. Furthermore product development times are long due to technological complexity and product safety regulations. As a result, previously made architectural decisions are not easily altered. When the company decided to create a new, modular, product architecture of elements of their scanner, they had the possibility to include the patient mover functionality. The company believed that this would benefit surgeons in a new application, thus creating a new market. The company chose to develop the functionality and customize every product to order. The method was applied to investigate if the company would include the patient mover into the product in the same way or that another decision would be taken in retrospect.

The floating tool case (FT case)

The floating tool was a feature of a different scanner in a similar medical market. The tool made it possible to make extra adjustments to the scanner and create a better image in an easier way. It was projected that a majority of the customers would pay extra for the feature. Therefore the functionality was developed and included in the product. The case investigated what would happen if other decisions like postponing the development would be made.

The analog to digital case (A2D case)

The analog to digital case consists of a vital part in a complex medical device which is currently based on analog technology. At the moment this technology is much cheaper than it emerging digital counterpart. However, the company projects that in the future the analog technology will become obsolete and more expensive than the digital technology. For the customer there is no direct benefit between the technologies. Therefore the technology does not affect sales. The company is decision which technology they should include in their new system. Based on the technology cost projects, the company can include the digital component to date or wait for several years. The method can be is applied to model these decisions.

How to apply the method

The method was split into four stages, which are indicated in purple in Exhibit 18. The stages are explained below. Afterwards, this chapter will discuss the introduction material and the model into detail.

Stage 1. Introduction material. All participants receive introduction material which introduces the subject of strategic decisions in product architecture very briefly. The material can be found in Appendix E. This way the participants get a similar knowledge base. Furthermore, it starts up the thinking process and thus creates commitment for the first group session. All participants that read the introduction material found the introduction material valuable (see PM case), since they recognized the four strategic decisions in product architecture (that will be explained in the next section).

Stage 2. First session. In this session all participants come together and define the business case, i.e. agree on the specific decision that is to be valued. The method is introduced and the method is applied for the first time with the inputs at hand. Participant get a feeling of the workings of the model. The group determines what kind of input is needed for their specific business case.

Stage 3. The consultant tailors the model to fit the business case at hand. The participants obtain the required input. Intermediate contact between participants and consultant is allowed.

Stage 4. Second session. The new input is inserted into the tailor made model. The model can be changed on the fly and decisions are evaluated in order to get insight in the financial effects of the business case.

Classification of four strategic decisions

The first step in valuating product architecture is identifying the opportunities that can be adopted into a product architecture. This was mainly done in stage 2: the first session. Architectural decisions usually concern a future market or technological trend, such as:

- What to do with a future upcoming market?
- Should the product be prepared for extra product variants?
- Should we incorporate a promising new technology?

For example, take a product platform that should last for the coming five years. The basic functionality of the product is known and a product architecture needs to be developed. However there are some possibilities that the consumer wants some extra features in the future, which they do not require now. This might be WLAN internet connection or an integrated RFID chip. Furthermore, the company might want to export to the Asian market in a couple of years, which requires some changes in the product. All of these opportunities are not profitable currently, but have potential in the future.

There are various ways to deal with these opportunities in a product architecture. However, a detailed architectural plan is often not required to make a decision. After all, the decisions are founded on the implications they have to the firm. Therefore, the most crucial architectural decisions concern the way the firm deals with these opportunities strategically. It thus depends on the market potential and costs whether or not to include a WLAN option. After that, a detailed architectural implication can be made. This reduction of technical details enhances communication between people from different disciplines which makes the joint creation of product architecture easier.

According to Philips AppTech, usually four strategic decisions can be made, as depicted in Exhibit 19.

Exhibit 19 – Four possible architectural decisions and some business function implications

These decisions will now be clarified using an example. For instance, take the example of including a WLAN chip into the product. There is a possibility that some people might require this functionality in the future and are willing to pay extra for it. Even worse, if you cannot offer this functionality, a number of customers will be lost to competitors. However, there is also a possibility that no customers will require the WLAN functionality at all. What to do?

Decision 1: Include in all

An option would be to include the WLAN chip standard in all products with a disabled functionality. Once the market requires the functionality, a company can launch it very fast and gain a good market share through its competitive advantage. Furthermore, there are little changes in the supply chain since the chip is already in the products. However, it comes at the cost of an extra component in all products. This money is lost, especially if eventually nobody requires the functionality. If the chip is not very expensive this might be a good option.

Decision 2: Prepare for the future

The second decision could be to build a preparation into the product. For instance, an interface for the WLAN chip could be made. If the market requires it, there will be already some preparations in the product and the time to market would be relatively fast as well (although probably not as great as when the chip was included). However, there will also be some redesign costs to implement the chip. This means that managers will only decide to launch the chip in the future, if it outweighs these implementation costs. Therefore, there is a possibility that the feature will not be launched at all. Then the costs of the interface should be seen as a loss.

Decision 3: Exclude in all

In some situations excluding functionality deliberately can lead to cost savings. However, the consequences are so drastically that it is virtually impossible to redesign the product and include the functionality in the future. For instance, discarding the WLAN functionality could require a cheaper computer system, but this is so integrated into the rest of the product that an entire new product has to be designed if the functionality is needed. It therefore in effect rules out any revenues of the new functionality.

Default decision 4: Do nothing

The final decision could be to not prepare for the future, but not excluding the possibilities for redesign that can save costs either. Essentially that is doing nothing and redesign if that was a bad choice. Of course this has the advantage that no costs are induced now and that is still possible to redesign the product with the feature. However, there are some tradeoffs. When the market requires the WLAN feature, the time to market is slow because the product needs to be redesigned first. Furthermore, redesigning usually comes at a relatively high cost: often higher than it would be to include the functionality in the initial product design.

Since a product architecture is determined for every product, one of these decisions is made for every option either implicitly or explicitly. Decision four is often the decision made by default. After all, paths of least resistance are often the ones take in organizations[7]. Since decision four requires no money initially and raises little discussion, it is plausible to say that it is the default choice in product architecture, when little attention is paid to architectural alternatives.

If no attention is paid to product architecture, decision four is the default choice

In all cases, the decisions were recognized. Furthermore, the idea of anticipating for potential features gave a new perspective on architecture:

"We did not do that, but we could have done that in retrospect" [PM 195] on including unprofitable, but promising, features into the architecture already.

"[P1] I don't think that in general we do these kind of things. [P2] No we certainly don't do this. […] Because this requires a different approach. [P2] We just either do things or don't." [PM 212].

Participants in the PM and FT cases recognized that decision 4 (do nothing) is often made as default:

"In practice, we just do four. […] And that means that if we then want to implement an option or a feature in retrospect (and we've got many examples of this), we often have to start all over again" [PM 219]

"because it is so hard, the decision is not made and we keep working on two things at the same time" [FT 52]

[7] Vroom's expectancy theory of motivation

Valuation of the four decisions

At this point, the four strategic decisions are known. This section describes how they will be valuated.

Uncertainty and choice in the four decisions

An important aspect of the four architectural decisions are choice and uncertainty. They are apparent in the following manner.

- Uncertainty. For all four decisions, it is hard to know the financial effects like costs, potential revenues, time to market gains, etc. At the utmost, business functions can just estimate these effects. Therefore, financial effects are more likely to be modelled by a range, than a specific value. Accordingly, uncertainty needs to be included in the valuation.
- Choice. The decisions 2 (prepare) and 4 (do nothing) are not predetermined investments. After all, the company has a future choice to implement the feature if the market turns out to be profitable. Therefore, the investment is staged: the company now decides to prepare for the WLAN chip and can decide later to bring to the market. The same goes for do nothing. The company can now decide to do nothing, and redesign the product if the market is profitable (although this probably will cost more). Accordingly, these architectural decisions are staged investments.

Choice is not only present in decisions in product architecture. It goes for all investment decisions that are staged. Furthermore, the requirement of initial investments for decision 1 (include in all) and 2 (prepare for the future) are also common properties that exist outside the field of product architecture as well. Exhibit 20 shows the way the four decisions map onto these aspects.

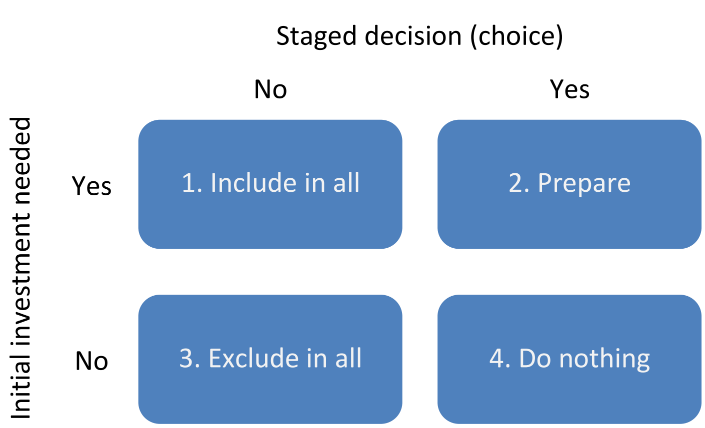


Exhibit 20 - Classification matrix of strategic decisions

A reader can imagine that the same type of decisions can be used for other domains. For example, decision 2 (prepare for the future) has resemblance with what Gil calls active safeguarding (Gil, 2007). Likewise, decision 4 (do nothing) can be seen as passive safeguarding and decision 3 (exclude in all) as no safeguarding. However, this thesis will focus on product architecture only and the four stated decisions.

Combining a decision tree with option thinking

Since uncertainty and choice are two important factors in the valuation of product architecture, real option theory seems the best way to value the investment in a market equivalent way. After all, decisions 2 and 4 for a WLAN chip create the right to enter a new market in the future. Since this market will only be entered if it is profitable in the future, the investment is similar to a call option.

In the previous sections it became clear that the no arbitrage violation is too strong to use option theory for product architecture. Architectural opportunities like WLAN investments are simply not traded, and this cannot be overcome by finding an equivalent portfolio. The profit of a WLAN option does not follow a GBM either. Furthermore, the Market Asset Disclaimer (MAD) does not hold either, since option theory is a worse representation of reality than the NPV in case of an incomplete market in investments in product architecture.

Option theory cannot be used for product architecture because

1. The non arbitrage principle does not hold since architectural opportunities are not traded
2. The profit does not follow a Geometric Brownian Motion
3. It is nearly impossible to find a equivalent portfolio in stocks that have the same risk and profit characteristics as the product architecture investment
4. The MAD does not hold

Since option theory cannot be used, uncertainty and choice are best modelled with a decision tree and discounted using the WACC (Borison, 2005). The error of using the same discount rate for different investment paths is taken for granted. However, the decision tree has the big disadvantage of becoming complex very fast. Therefore, only a very simple tree will be used. Later on this is combined with an adapted form of options theory, that does not use the non arbitrage principle or a assumes a GBM, but only adopts a similar way of options thinking. This way, the methods aims to keep the method simple, just as real option theory does with the Black-Scholes equation. For now the start of the decision tree is constructed. Then it is shown that instead of expanding the tree, a part of it is being replaced with a form of options thinking. This will be elaborated further.

The four decisions in a decision tree

Since a decision tree cannot model all possibilities, it is imperative to model the most crucial choices and probabilities. As indicated, a decision 2 and 4 have essentially two decision stages: (1) the decision to anticipate the product architecture for the feature and (2) to launch the feature on the market in the future. Since the framework aims for simplicity the tree will be limited to only these stages.

The tree starts with the four strategic decisions since they are the most crucial for the architecture. This is depicted in Exhibit 21.

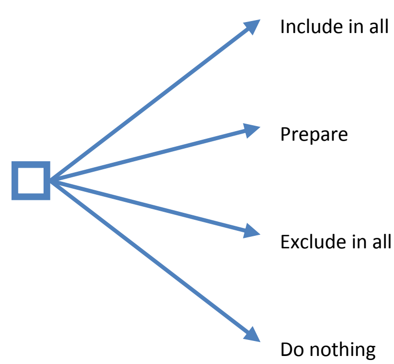


Exhibit 21 - The four decisions in a decision tree

The next crucial uncertainty is the year in which the market would demand the WLAN feature. It is often very hard to determine if and when the market would like to have a specific feature in the future. For instance, a business function might indicate a potential WLAN feature demand in a couple of years, but they can only roughly tell in what year this will be the case. Even more, sometimes it is not even certain if a feature will be demanded anyway. Since the estimation greatly influences the expected profit in terms of total years of sales, this estimation forms the basis for the tree. The four decisions can then be modelled like Exhibit 22.

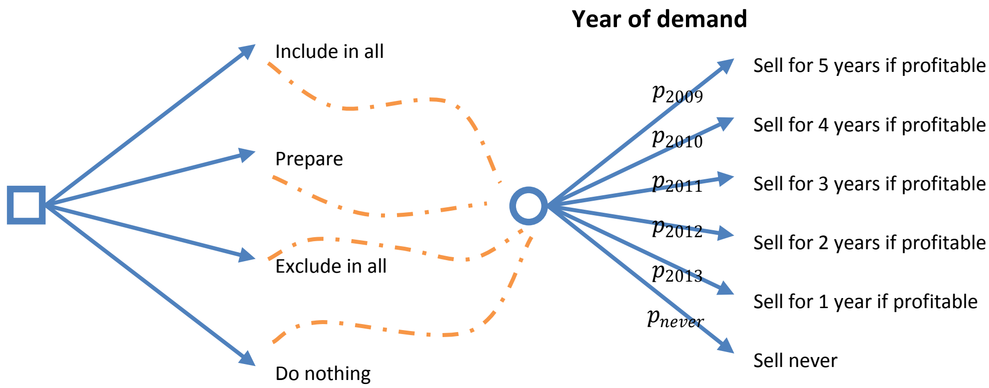


Exhibit 22 - Decision tree with uncertainty of the year of market demand

In this example there is a possibility that the WLAN feature is demanded in 2009, 2010, 2011, 2012, 2013 or never. Naturally, this can be extended to many more years.

In order to get a single value for each decision, the probabilities of market demand for each year need to be known. During the early test phase of the method, this did not always turn out to be intuitive. Therefore, this was not done in any of the cases. Instead, the results of demand each year were directly shown to participants. However, if these probabilities need to be estimated, this can be done best if the probabilities are asked cumulative. Thus a product manager is asked the following:

Could you indicate the probability that the market wants the feature by year xxx?

The probabilities can then be visualized in a cumulative probability chart, such as in Exhibit 23.

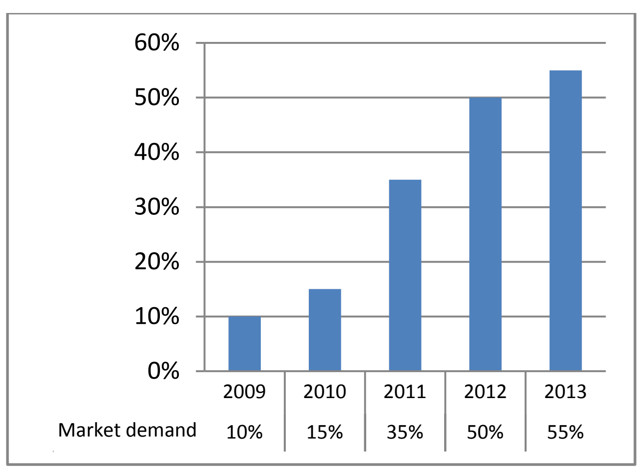


Exhibit 23 - Cumulative probability c_i of market damand in year i

Through the visualization crucial years become visible in sudden jumps. For instance, in this example the chart indicates that the expected WLAN feature is likely to occur by the year 2011. Furthermore, the chance that the feature is not demanded becomes clear as well. In the example there is a 100%-55%=45% chance that there is still no market demand by 2013: the end of the architecture lifetime. Thus the model also accounts for the possibility of no market demand at all.

With the cumulative probability estimations, it is easy to calculate the probability of market acceptance per year by taking the difference from the previous year. This is stated in Equation 4. The chance for no demand at all is given in Equation 5.

$$p_i = \begin{cases} 0 & i < first\ year \\ c_i & i = first\ year \\ c_i - c_{i-1} & first\ year < i \leq last\ year \end{cases}$$

p_i: Probability of market acceptance at year i

c_i: Cumulative probability of market acceptance up to year i

Equation 4

$$p_{never} = 1 - c_{last\ year}$$

Equation 5

Finally, these probabilities are inserted into the decision tree of Exhibit 22. Each branch in the decision tree indicates the probability that the market demands the feature exactly at that year. In the example, the company estimates a 10% chance that the market requires a Wifi feature in year 2009, a 5% chance in year 2010, a 20% in year 2011, and so forth.

One may argue that these probabilities cannot be accurate, since they are only estimates. Thus there the error margin in these numbers is significant. This is correct. However, one must recall that this method intends to lead to better architectural decisions. Currently, many of these decisions are usually made without any financial evaluation at all. They are based on a gut feeling which was also apparent in multiple cases:

“I am then struggling with the financial arguments during the decision process. Because these were not present.” [A2D 69]

“in the feature business I don’t think there are any NPVs made at all” [FT 37]

Recall that in those cases decision four (do noting) is the default choice. Therefore, this study aims to get the best results with the knowledge at hand. After all, this is better than not evaluating architectures at all. However, because of the high error margin there is no justification to model any sophistications, except for the dominant effects.

Including uncertainty and choice in the decision tree

Once there is a market demand, the company has to make its second decision: will the company launch the feature or not? Of course this depends on whether they will make a profit on it. After all there may be a market demand, but the initial investment may still outweigh the profit, resulting in a net loss.

For instance, take the following simplified example of the WLAN feature. In case the company decides to prepare for the feature, there are some possible profits S that occur in each year of demand. It already made some costs for the preparation, but they will now be disregarded for illustrative purposes. In the model this is accounted for as will show later. For each decision, the possible profits and their chances are different. After all, they all have their own cost characteristics and time to market effects. Say that in order to launch a prepared feature the company has to pay $K = €300$ implementation costs. The same costs goes for redesigning a *do nothing* feature for simplicity. In that case it would not be profitable to launch the feature for €300 if the expected profit from the feature only equals €100. After all, the net profit would be negative ($S - K = -€200$). Only if management expects a positive profit, it decides to launch the feature.

For decision 2 (prepare) and 4 (do nothing), this staged choice is possible. Therefore a decision node is added in the decision tree. This node indicates the choice to launch the feature. Management will market the WLAN feature, if the profit at the end of the arrow is higher than the investment K. Accordingly, an extra branch with choice is added after each branch in the starting tree. In case of decision 1 (include in all) and 3 (exclude in all), no second choice is possible. For these decisions, a branch is added without managerial choice. This is illustrated in Exhibit 24.

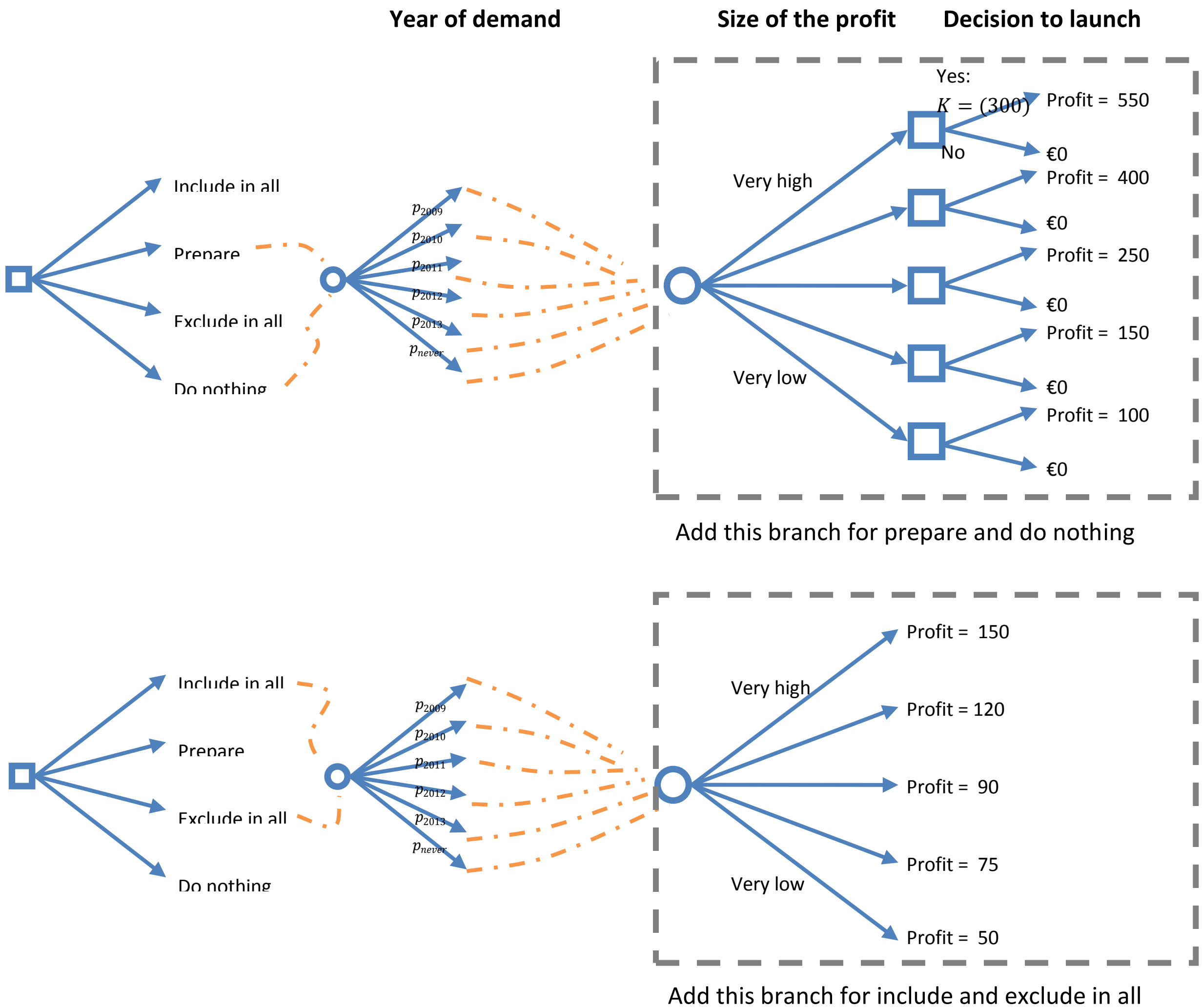


Exhibit 24 - Extra branch to account for five possible profit paths

The valuation above is only correct if all probabilities and profits are estimated correctly. Therefore, the profit and corresponding probability need to be determined for each feasible scenario. This is a complicated and unintuitive task. After all, hundreds or even thousands of paths are needed to include all uncertainties of the future. Exhibit 25 illustrates that even for five years and a limited amount of profit outcomes, this decision tree becomes very complex.

Because of this complexity, the method becomes impractical. Business function do not want and often cannot identify all paths. Therefore the extra branches are replaced by a way that asks for a more intuitive input. However, it gets the same results as thousands of paths. This is done using a Monte Carlo simulation that borrows the option thinking from option theory.

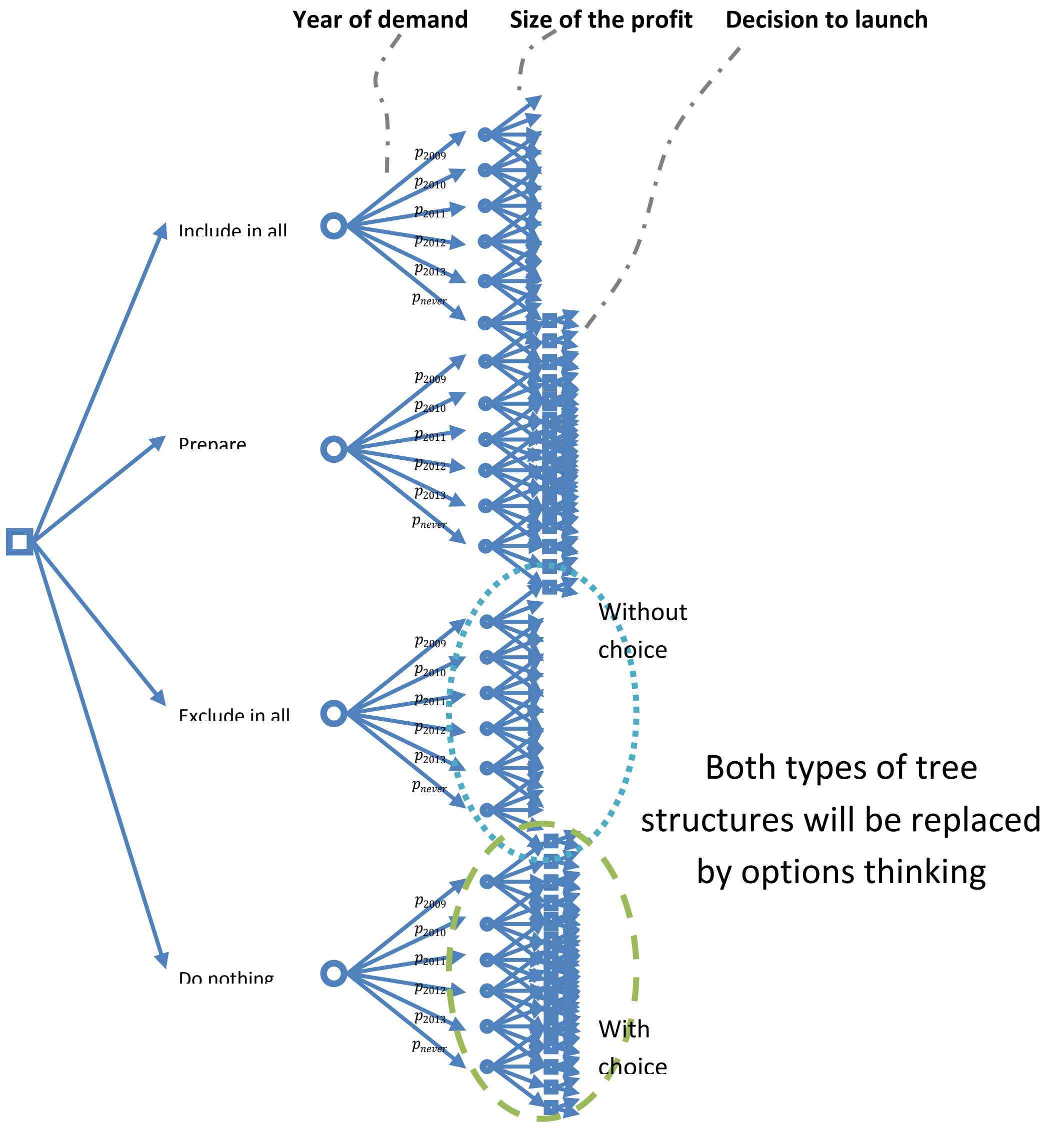


Exhibit 25 - Tree with five profit paths per decision

Replacing part of the decision tree by options thinking

Both types of tree structures will now be replaced by what we well call option thinking. Recall from option theory that the option value can be determined by simulating the risk neutral stock prices. Then the option value is just the expected profit above the strike price. A similar approach will be used, without a GBM or the non arbitrage assumption. It will now be illustrated how this approach equals the extra branches of Exhibit 25. We first start with the tree structure without choice.

Replacing the tree structure WITHOUT choice by options thinking

A continuous probability distribution of profits can be approximated by a histogram. This is illustrated in Exhibit 26. In this picture a lognormal shape is taken for illustrative purposes since it is similar to a GBM in option theory. Any other shape suffices as well. The probability distribution is split in to bins. Each bin indicates a profit range that starts from the previous bin and ends at the indicated number. The height of the bar indicates the chance that the profit falls within this range. Thus in the example there is a 0,4 chance that the profit will be between €50 and €200 Therefore one could also say it has a 40% chance to be the average of €125.

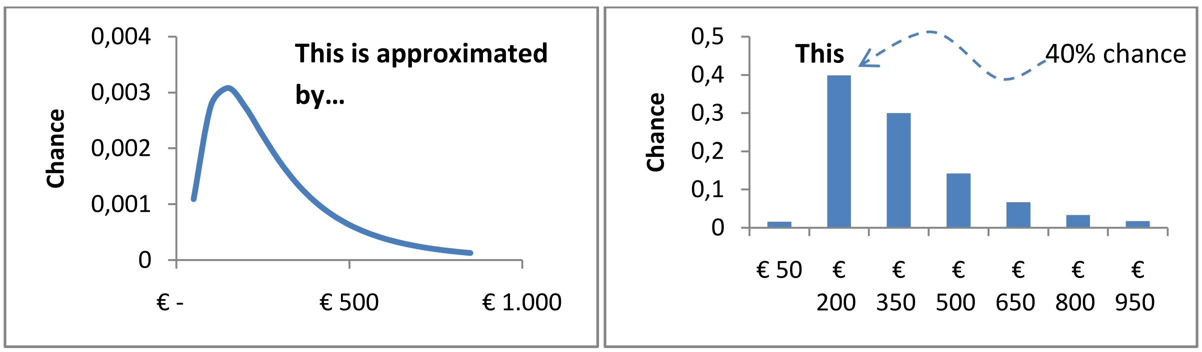


Exhibit 26 – Approximation of a continuous probability distribution by a histogram

In the example, there are only seven bins. Therefore the range of the values is very big and the approximation is not very good. However if the number of bins is increased, the approximation becomes better. Also the range becomes smaller.

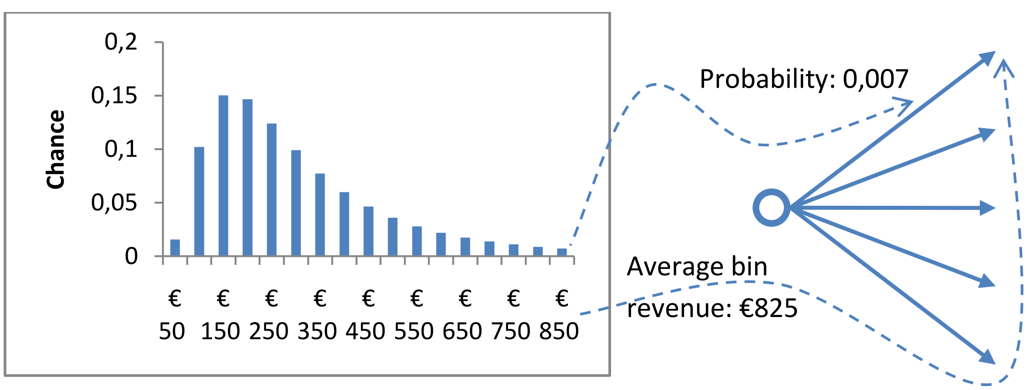


Exhibit 27 - Histogram with more bins and its mapping to the decision tree

In Exhibit 27 the number of bins is increased to 17. Each bin only has a range of €50. So in the example there is a 15% chance that the profit will be between €100 and €150, averaged €125. If the number of bins increases, the ranges will almost be the same number and the histogram almost equals the continuous probability distribution. Therefore, the more bins, the better the approximation. This can also be seen in the example. Clearly the 17 bins approximate the distribution better than the 7 bins.

Since profit and chances can be determined from a probability distribution, they can also be mapped to a decision tree. This is illustrated on the right side in Exhibit 27. To do so, the probability from a histogram bar equals the probability of a profit branch. Finally the profits equal the average value from the range of the bin. This is indicated with striped arrows in Exhibit 27. Recall from Equation 2 that the value of an uncertainty node equals the chance times the profit for all branches. Chance times profit is exactly the height of one bar times the average bin value in the probability distribution. Thus the value of the node equals the average of the area in Exhibit 28.

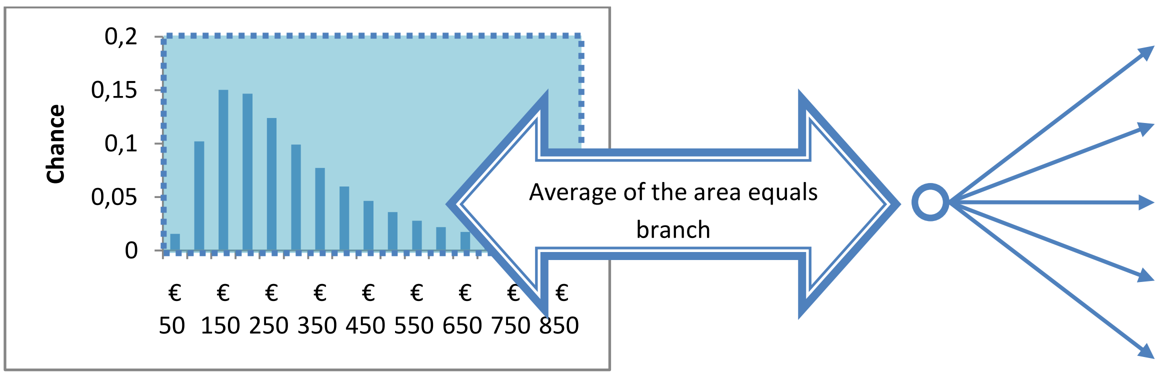


Exhibit 28 - The average of a probability distribution equals an uncertainty node value

Replacing the tree structure WITH choice by options thinking

The tree structure with choice can be replaced in a similar way as above, by applying options thinking. Recall that the example feature will not be launched if the initial investment K is higher than the profits S, indicated by individual bars in the histogram. Thus only, the profits above $K = 300$ will be profitable, indicated by the area of profit in the left part of Exhibit 29.

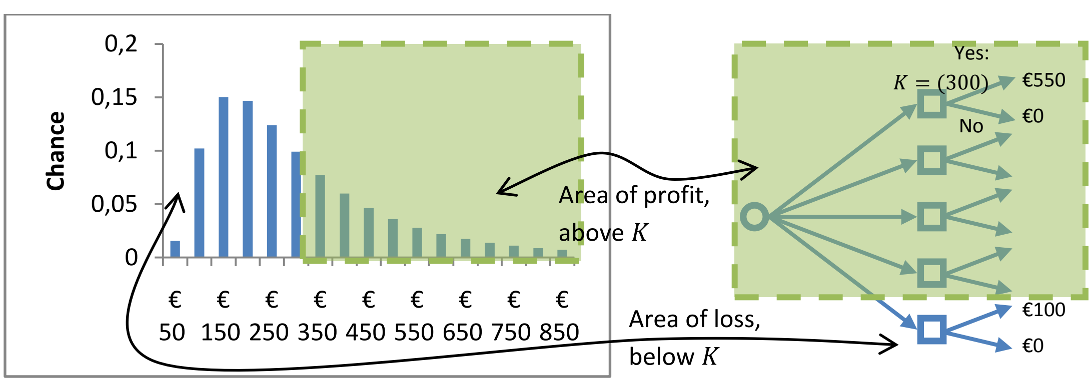


Exhibit 29 - The average of the area above the investment minus the investment itself equals the decision tree branch

In case of profits below this point, a net loss will be made and management will decide not to implement the feature. Therefore the expected profit equals the average of the area above K, with investment K subtracted from it. This represents the tree structure with choice, indicated in the right of Exhibit 29.

Options thinking can be applied to this profit distribution and will give the distribution of the net profit, after initial investment K. Recall from option theory (explained in Appendix B) that this means applying Equation 6.

$$\max(S_i - K; 0) \quad \forall i$$

Equation 6

i: Number of the bin

S_i: The average profit of bin i

K: The investment needed to launch

Once the equation is applied, a net profit distribution is created of which the average value represents a branch with the decision nodes. This is illustrated in Exhibit 30.

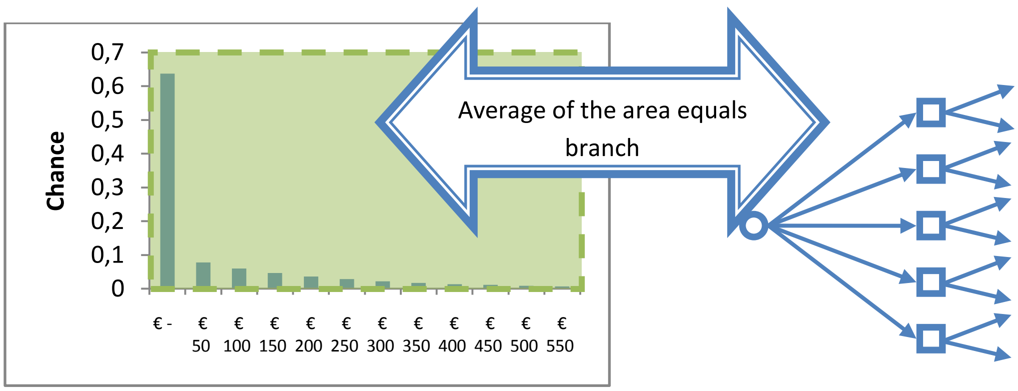


Exhibit 30- The average of a probability distribution after options thinking equals an decision node value

This procedure is identical to option theory by simulation. The area above the investment determines the option value, which equals the average of the distribution after Equation 6. Because of the resemblance, this is referred to as options thinking. The difference however lies in the determination of the probability distribution. In option theory a risk neutral GBM determines the distribution: the GBM leads to a lognormal distribution and the risk neutral adjustment incorporates the no arbitrage principle. Since these assumptions do not apply for product architecture, the distribution will be determined differently and discounted using a cost of capital.

In the implementation of the method in the rest of this chapter, no explicit separation will be made between profits S and implementation cost K like in Exhibit 29. Instead the net profits of the decision *lauch/do not lauch* will be calculated directly. All costs like implementation cost K will thus be included in the end node and the following option thinking rule will be used: $\max(P_{lauc\ h}; P_{do\ not\ launc\ h})$ in which P represents the net profit of a decision after all costs (K and all the costs in the preceding branches). This gives the benefit of easy implementation. However, it does not affect the results at all.

The final model of valuation

At this point the complete model to value architectural decisions is known. It is depicted in Exhibit 31 and will now be explained. First one has to realize again that we are in fact valuing four options: all four decisions. All of these options represent some value. Although many might not realize it daily, even decision 4 (do nothing) represents value, which is essentially keeping the option of redesign open. Therefore, the difference in value is important, since it shows which decision is best given the uncertainty of the future.

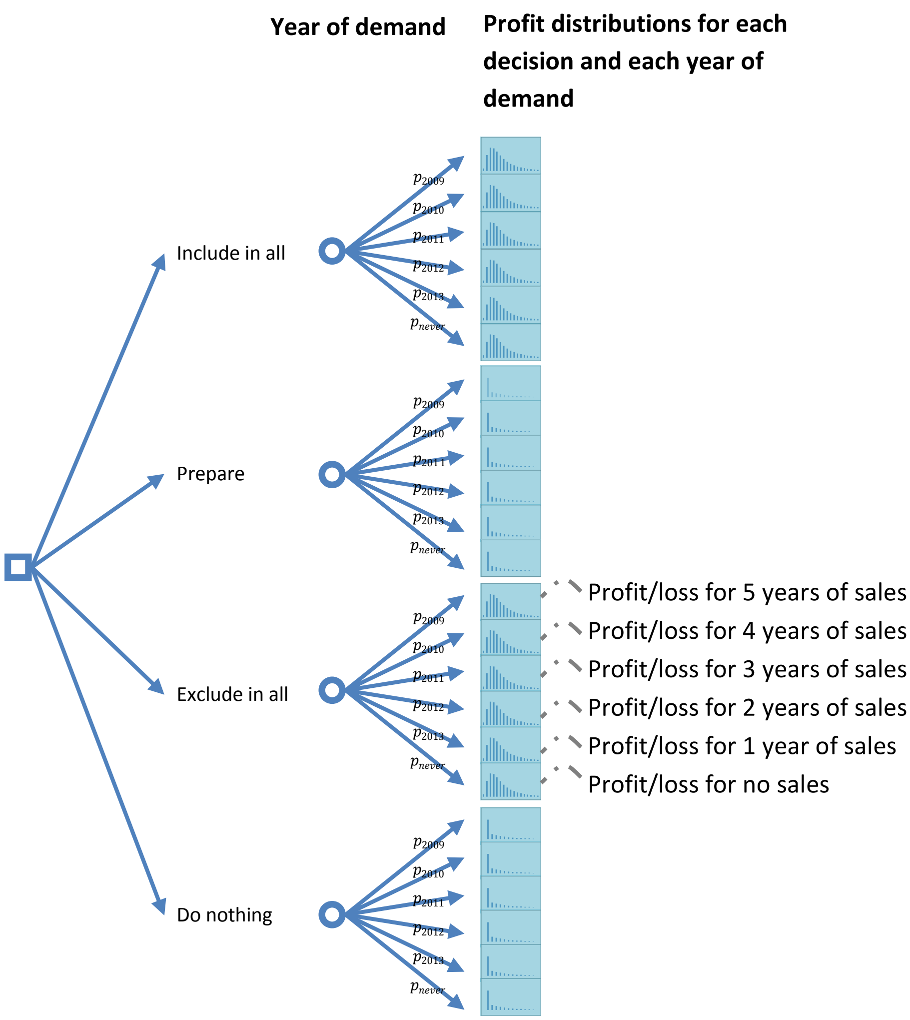


Exhibit 31 – Final model to value strategic architectural decisions

All decisions need to be valued in order to compare them. This is done in the following manner. Each year there is a possibility that the market requires the feature. The probabilities are based on the cumulative probability chart from Exhibit 23. If the market requires the feature, model assumes that the company can sell it the entire product architectural lifetime. However the company will only launch the feature if the net result of launching is higher than the result of not launching. This choice is possible for decision 2 (prepare) and 4 (do nothing). For each decision and each year of market demand a profit distribution is generated. The average value replaces the node value. Finally, this expected profit can be multiplied with the probabilities of market acceptance p_i. However, as seen in all cases, the average values and profit distributions give insight themselves as well.

In order to determine the profit distribution, a Monte Carlo simulation will be used that includes choice for decision 2 (prepare) and 4 (do nothing). This can be done in any way and as detailed as desired. However, the model tends to keep the input to a minimum and enable practical use. The next section explains the implementation of the method in Excel and its underlying language Visual Basic for Applications (VBA). This it will indicate how these distributions can be determined intuitively and how this was perceived by participants in cases.

Implementation of the method

The current section describes the relations that are used in the Excel and Visual Basic implementation. Aim was to create a model that fits many different architectural problems easily, whist not becoming too complex. Relations were based on feedback during the development of the method and case applications. The input of the model is described first, followed by the calculations and model output.

Model input

The input of the model is split into market modelling and decision modelling. After all, the market response is indifferent to the way the company offers the feature. The method tried to limit the number of inputs, without being too general. In the PM and FT cases this worked out well:

"Everything is included. At least the things that we include normally" [PM 564] and [A2D 136]

Nevertheless, the A2D case needed some model adaption which is discussed later. The input variables are now defined and commented if appropriate.

Market modelling

Market modelling could be done directly in Excel. The most important results were graphically shown at a real time base. The graphical interface helped participant to directly see effects [FT 100] and stimulated discussion [PM 331]. It is illustrated in Exhibit 32. The input is explained in the section below.

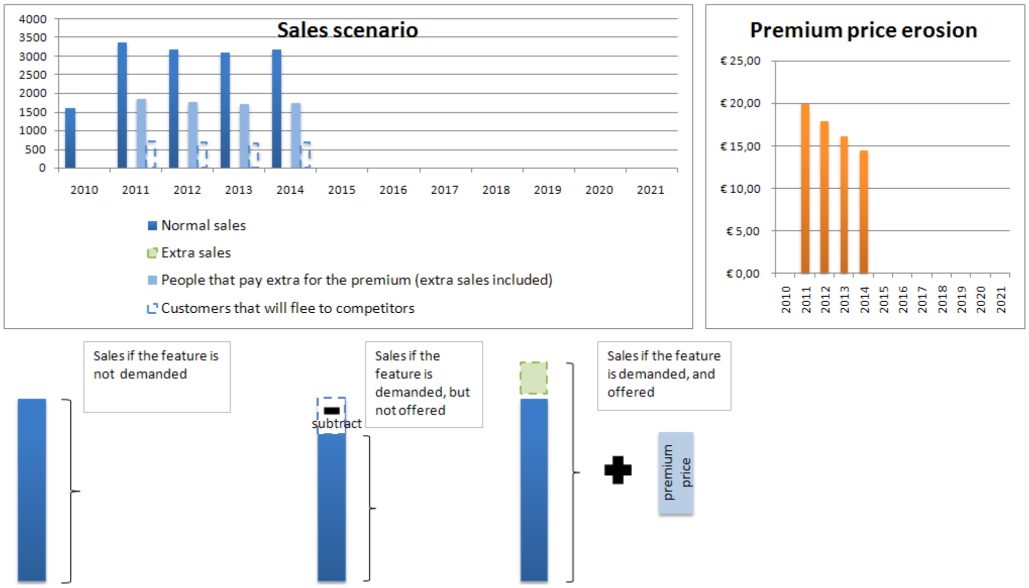


Exhibit 32 - Market modelling in Excel

Base case

n_i	Total products sold in year i	The total of product that will be sold in year i
P_i	Profit per product in year i	The profit per product in year i

AppTech indicated that in many cases, product managers or marketeers have a base case forecasting in terms of profit and number of products sold. This forecasting should be done for the architectural lifetime. After all, once a new product architecture will be developed, the four decisions can be made again. In both the FT case and the PM case, the numbers above were easily available. These numbers are important to calculate the extra profit in case of extra systems and to calculate customer fleeing to competitors. Furthermore, the total profit can be compared with the final results in order to place the results into perspective.

In case of market demand and the company **can** offer the feature

p_{extra}	Percentage extra products	The percentage of extra products that will be sold if the feature is offered. All of these products are expected to pay the premium $P_{premium}$ as well
$p_{premium}$	Percentage that pay a premium	The percentage of the current products that will pay an extra premium price for the feature and generate an extra premium profit $P_{premium}$
$P_{premium}$	Premium profit per product	The extra profit per product that is sold with the feature in the first year of market demand

e	Premium price erosion	The percentage of the premium that drops per year after the first year of market demand

Usually an architectural investment can lead to the sales of more products or generate extra revenues. Sometimes a combination is possible as well. The parameters are only required if the effect is expected. In both the FT and the PM case, participants foresaw a price erosion themselves [FT 97].

In case of market demand and the company **cannot** offer the feature

p_{flee}	Percentage that flees to competitors	The percentage of the products that will not be sold anymore, because customers flee to competitors that can offer the feature
T_{flee}	Time before fleeing	The time before fleeing occurs after the first year of market demand

During a preliminary test case at AppTech, it became apparent that functionalities are not always included to generate extra profit, but also to reduce loss. Many safety systems of cars like airbags and Anti-lock Braking Systems (ABS) are examples of this. Customers will not pay much more for it, but will eventually go to competitors if the company cannot offer it. This view was also supported in the cases [PM 237] [PM 289] [AD 8].

General settings

Y	Year of demand	The year in which the market demands the feature
r	Weighted Average Cost of Capital (WACC)	The industry specific cost of capital of a project with normal risk

The year of demand can be set to determine the input distributions at a specific year. For the simulation, all years of the architectural lifetime will be evaluated. The WACC is incorrect since the inclusion of choice leads to investment paths with lower risk characteristics just like in a decision tree (Chapter 4, pp. 64). Therefore the WACC should be adjusted downwards. On the other hand, high discount rates underestimate big investments in the future. Since this is often the case in staged investments, the valuation can be too optimistic. These problems are no different from a DTA or NPV valuation. Because of a lack of better alternatives, the WACC will be used. Discussions at AppTech and at cases [PM 210] showed that it is common practice to use this discount rate in other valuations as well, which has the benefit that many people are familiar with the concept. Nevertheless, like in any valuation, users should use the results as an aid and should never follow them blindly.

Decisions modelling

The decisions were inputted in Excel as well. The input was shown graphically similar to the market modelling. It is depicted in Exhibit 33. The variables are explained afterwards.

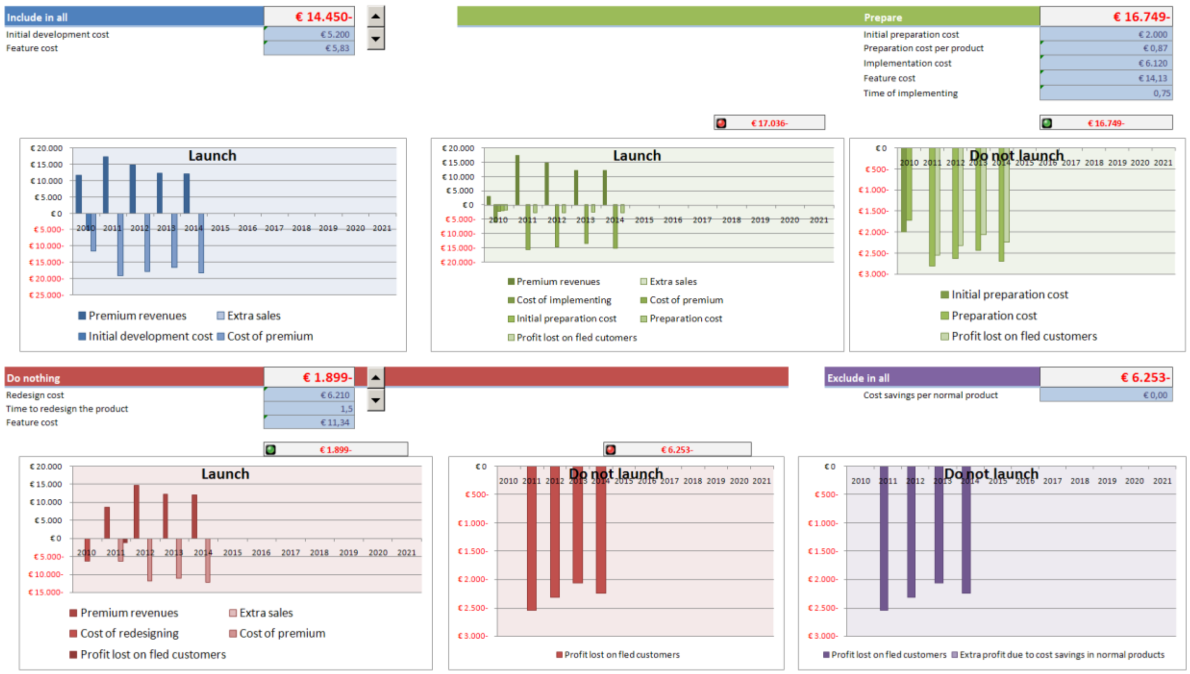


Exhibit 33 - Decisions modelling in Excel

Include in all (decision 1)

$C_{init,incl}$	Initial development cost	The initial costs made to include the feature in all products
$c_{f,incl}$	Feature cost per product	The cost per product to include the feature in all products

This decision is not staged. The costs to include the feature will be made for every product sold, regardless of the market demand. Since the feature will be included in all products, the model assumes that the company can offer the feature immediately once there is a market demand.

Prepare for the future (decision 2)

$C_{init,prep}$	Initial preparation cost	The initial costs made to create a preparation for the feature in all products
$c_{p,prep}$	Preparation cost per product	The cost per product to include a preparation for the feature
$C_{I,prep}$	Implementation cost	The implementation costs to launch products with the feature

$c_{f,prep}$	Feature cost per product	The cost per product with a feature after implementation
t_{prep}	Time of implementing	The time to market delay between the decision to launch the feature and the first sales

This decision is staged. Therefore there are two costs: the cost of preparation and the costs of implementation. Furthermore a time to market effect is introduced. This time effect was recognized by all participants of the cases. It is also congruent with literature, indicating that financial effects in architecture mainly exist in costs and time (Boer, et al., 1999).

Exclude in all (decision 3)

S_{excl}	Initial cost savings	The costs that are saved compared to doing nothing by excluding the possibility to redesign the product
s_{excl}	Cost savings per product	The cost savings per product by excluding the possibility to redesign the product for the feature

The decision to exclude functionality only provided cost savings in a limited amount of cases. Again this decision is not staged.

Do nothing (decision 4)

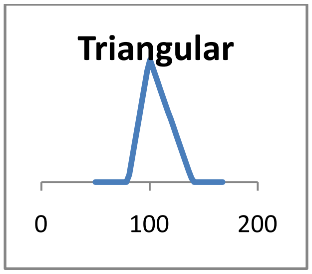
$C_{redesign\ ,not\ h}$	Redesign cost	The onetime costs to redesign the product for the feature
$c_{f,not\ h}$	Feature cost per product	The cost per product with a feature after redesign
$t_{not\ h}$	Time of redesigning	The time to market delay between the decision to redesign for the feature and the first sales

This decision has the same input as prepare, without any preparation costs.

Uncertainty

As mentioned many cost and revenue figures are just best educated guesses. Therefore it is not always possible or easy to give static numbers. Therefore people can use ranges for numbers that suit their estimates best. The input distributions in Exhibit 34 are implemented in the model. The distribution functions can be found in Appendix G.

The triangular distribution is often used when there is few or no data (Winston, 2004 p. 1166). The uniform distribution is used if there is really no information on the behaviour of the range. The statements below the distributions indicate how an intuitive estimate is translated into a distribution. As one can tell, the required input is restricted to a minimum. People can deliver the data in a way they are most comfortable with.



I think the selling price will be between €80 and €140. However, €100 is most likely

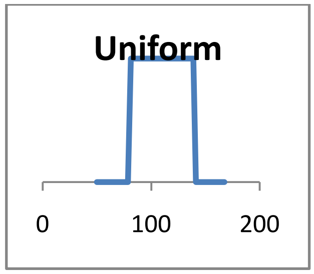
Required input

Minimum value a

Maximum value b

Most likely value c

Notation: $T(a; c; b)$



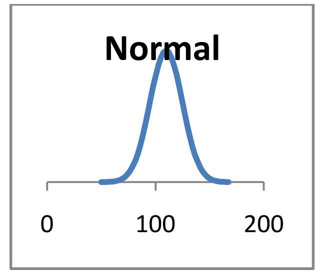
I think the selling price will be between €80 and €140, but don't have a clue what is most likely

Required input

Minimum value a

Maximum value b

Notation: $U(a; b)$



I did some market research and think the average price will be €110 with a standard deviation of €15

Required input

μ_{norm} : average

σ_{norm} : standard deviation

Notation: $N(\mu_{norm}\,; \sigma_{norm}\,)$

Exhibit 34 - Input distributions for the Monte Carlo simulation

Every variable can be replaced by an input distribution if desired. A simple user interface was created for fast and intuitive input. The implementation of it in Visual Basic can be found in Appendix I.

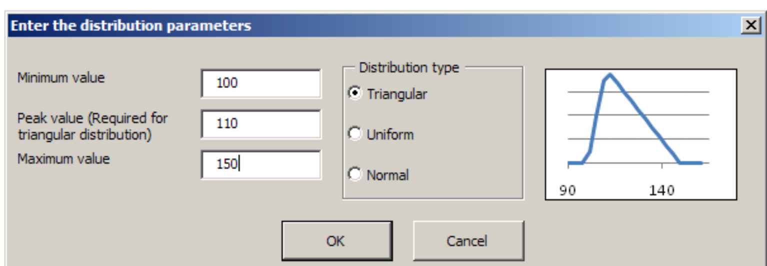


Exhibit 35 – User interface to input uncertainty

With this data the profit distributions in Exhibit 31 can be simulated. All participants in the cases liked to include uncertainty instead of a fixed number:

"I think it might have some benefits since at the NPV, we always assume it's a fixed number. Well actually, that's a Utopia." [PM 345]

Furthermore, all participants got used to inputting values with uncertainty, since the speed of it increased in all cases. Both in the PM and the A2D case, participants addressed the concept of fake certainty [PM 154] and saw a value for including uncertainty:

"because it indicates, also to the manager, that there is still some uncertainty in a decision. […]However if you show him three specific points, It seems that one is better. And that is a fake certainty." [A2D 120-124].

Input flexibility

One of the main requirements of the method is a practical applicability. Therefore the model tried to find a balance between the ease of predetermined relations and flexibility to alter the model to specific situations. The ease of altering was one of the main reasons to implement the model in Excel. After all, the method is not meant to be rigid but to be easily customized if needed (see Exhibit 18).

During all cases the Excel flexibility was used to create correlated relations between variables. The A2D case showed that the model can be adapted with a relative ease as well. Two examples will illustrate the flexibility of the model.

Correlated relations

Variables do not have to be independent. In the PM case and the FT case, a variable market growth was modelled very fast. For instance, take the products sold n. Participants could make an intuitive estimation of market growth, as stated in

Total products sold	2009	Between 200 and 250
	2010-2012	Between 102% and 110% of the previous year. The most likely value is 106%
	2013-2014	Between 97% and 103% of the previous year

Exhibit 36 – Example of correlated estimations

This is mathematically modelled in Exhibit 37. The figure on the right shows some random sample paths. Trends and random fluctuations can be modelled easily, just like a GBM does with drift μ and volatility σ. However this approach gives greater flexibility in addition, is more intuitive and is able to model reality better.

$$n_i = \begin{cases} U(200; 250) & i = 2009 \\ n_{i-1} * T(1{,}02; 1{,}06; 1{,}1) & 2010 \leq i \leq 2012 \\ n_{i-1} * U(0{,}97; 1{,}03) & 2013 \leq i \leq 2014 \end{cases}$$

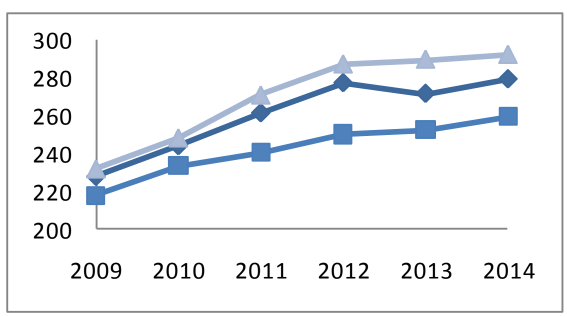


Exhibit 37 – Mathematics and three sample paths of the correlated estimations

Model adaption

During the A2D case, a critical variable was the cost development of specific parts. The method was adapted within an hour in order to include this behaviour within the distributions of Exhibit 31. Some sample paths of the cost development are depicted below. A similar adaption can be made for other cases.

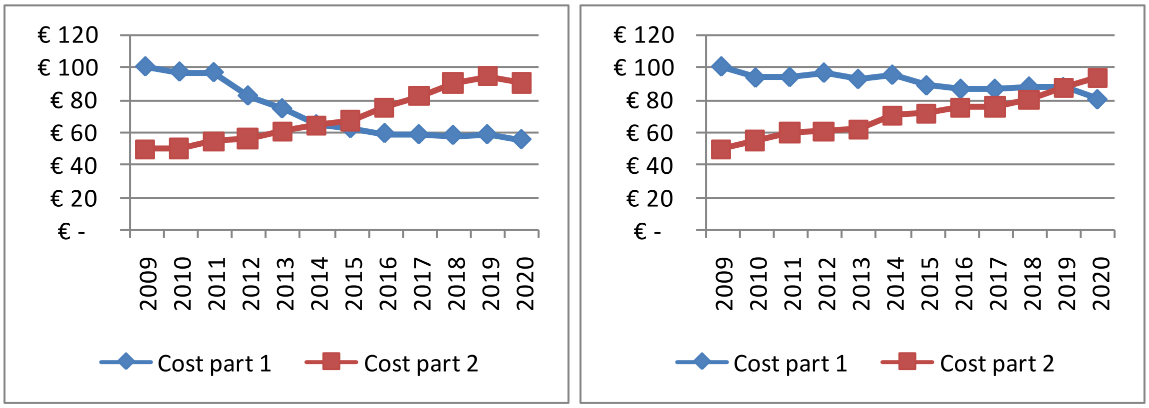
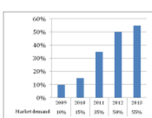


Exhibit 38 - Adaption of the model to include specific cost behaviour

A summary of the input for the user

Based on what was discussed above, the method may look rather complex. However, many of the text explains why the method is constructed in a specific manner. Notice that the input requirements for the user are relatively low. After all, only the following issues are needed:



1. Once: An estimation of the market acceptance probabilities p_i.
   (optional: skipped at all cases)

2. Once: Basic market behaviour estimations

3. Per decision:
   a. Basic estimations of cost effects
   b. Basic estimations of time to market effects

Model calculations

The current section shows the mathematical relations and the simulation that were implemented in the model.

Mathematical relations

Each of the four decisions has a final calculation that determines the profit/loss in a specific year of demand Y. Since the formulas are based on the input variables on pp. 64, the results differ all the time. After all, the variables can be fixed numbers, but also distributions like $T(1;2;3)$ or $U(2;5)$. The final formulas are stated below. The results will be recorded in the Monte Carlo simulation and determine the distributions in Exhibit 31. Detailed formulas are stated in Appendix H. The following assumptions are made.

- All cash flows in a year will be discounted for a full year
- Only revenue and costs that occur within the architectural lifetime are included
- Companies are assumed to be risk neutral (i.e. no utility function is included that compensates for risk avoiding behaviour)

Include in all

$$ResultIncl_Y = PremiumRevenues_Y + ExtraSales_Y - InitialDevCost_Y - CostOfFeature_Y$$

Prepare

$$\begin{aligned} PrepareProfit_{Y,launch} &= PremiumRevenues_{Y,launch} + ExtraSales_{Y,launch} - CostOfFeature_{Y,launch} \\ &\quad - ProfitLostFledCustomers_{Y,launch} - PrepCost_{Y,launch} - ImplementingCost_Y \\ &\quad - InitialPrepCost_Y \end{aligned}$$

$$PrepareProfit_{Y,noLaunch} = -InitialPrepCost_Y - PrepCost_{Y,noLaunch} - ProfitLostFledCustomers_{Y,noLaunch}$$

Apply options thinking

$$PrepareResult_Y = \max\left(PrepareProfit_{Y,noLaunch}; PrepareProfit_{Y,launch}\right)$$

Exclude in all

$$ExcludeResult_Y = InitialCostSavings_Y + SavingsOnProducts_Y - ProfitLostFledCustomers_Y$$

Do nothing

$$NothingProfit_{Y,noLaunch} = ProfitLostFledCustomers_{Y,noLaunch}$$

$$\begin{aligned} NothingProfit_{Y,launch} &= PremiumRevenues_{Y,launch} + ExtraSales_{Y,launch} - CostOfFeature_{Y,launch} \\ &\quad - ProfitLostFledCustomers_{Y,launch} - RedesignCost_Y \end{aligned}$$

Apply options thinking

$$NothingResult_Y = \max\left(NothingProfit_{Y,noLaunch}; NothingProfit_{Y,launch}\right)$$

The simulation

An example will now show how the simulation is performed for fictive inputs. The year of demand Y is 2009 and the simulation is run for 10 times. This number of iterations is way too low to give accurate results, but it does illustrate the workings of the simulation. A histogram of the simulated data represents the distributions in Exhibit 39. The data of the simulations is after option thinking. Furthermore, every number has the same chance of occurrence. Therefore, the average of the all data equals the distribution averages. The same can be done for all years of market demand to obtain values for each endpoint of the tree.

	$Result\ Incl_{2009}$	$Prepare\ Result_{2009}$	$Exclude\ Result_{2009}$	$Nothing\ Result_{2009}$
run 1	36-	173	110-	138-
run 2	505-	205-	34-	62-
run 3	169-	218	381-	167
run 4	365-	99-	453-	459-
run 5	314-	101	73-	9-
run 6	761-	334-	624-	263-
run 7	99	274	192-	11-
run 8	334-	133-	51-	77-
run 9	169-	40-	58-	96-
run 10	44-	73	480-	297-
average	**260-**	**3**	**246-**	**125-**

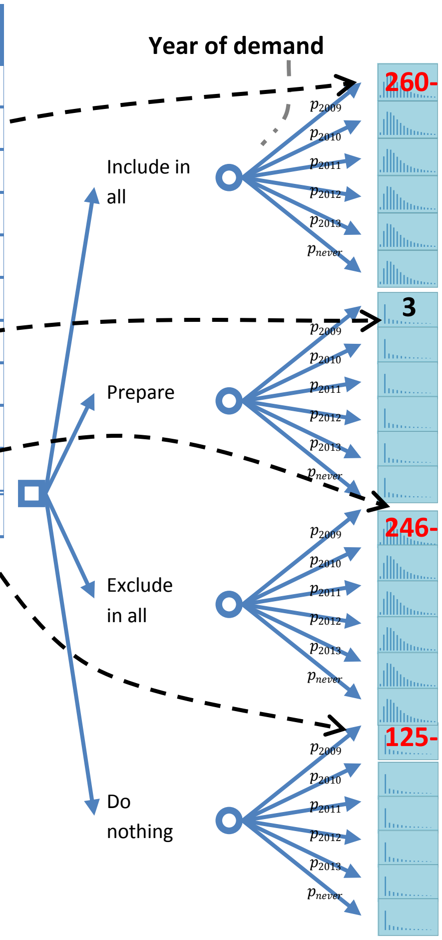


Exhibit 39 – Simulation of 10 iterations for market demand in 2009 and its mapping on the model

The simulation was implemented in Visual Basic and can be found in Appendix J. Other functions that invoke the simulation or facilitate the user interface are stated in Appendix I and Appendix K.

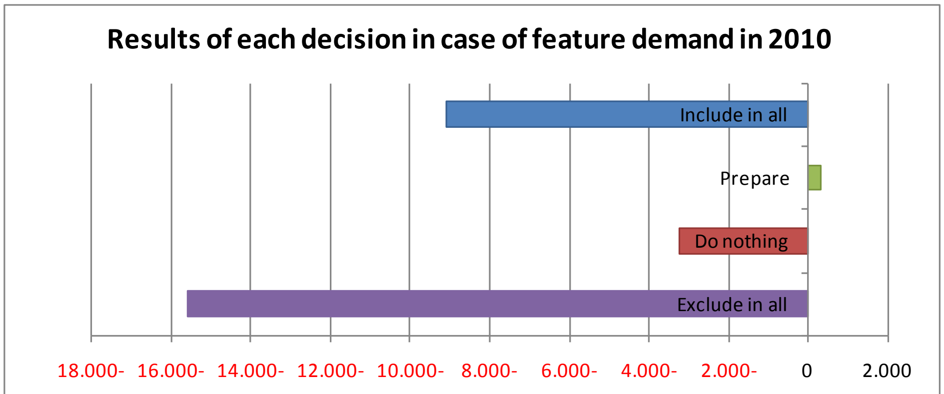
Model output

In general, it took some time for participants to understand the model and relate it to their business case. Cases showed that the information should be presented in little doses to participants to help them understand the workings of the model faster. It showed that more information can be presented easily, once participants ask for it themselves. For instance, in the PM case the results of all years were shown from the start. This took significantly more time to understand than in the FT and A2D cases, where the results of the most likely year were shown first.

During none of the cases, the probabilities of Exhibit 23 were estimated to determine the value per decision. This probably had to do with the learning process as well. After all, these probabilities will be easier to estimate once participants understand the year of demand variable. Furthermore, these probabilities may not be needed at all. After all, participants were not so interested in a model giving them a single value or an optimal decision. Instead, they wanted get insight in the decisions [PM 454]. This section will now describe the model output that participant saw using an example.

Results of an example case

Unfortunately it was not possible use figures of a real case because of confidentiality. Since the method models non linear behaviour, it is hard to replicate the results with alternative numbers. Therefore the results are shown of a fictive project. This is depicted in Exhibit 40 for year of demand $Y = 2010$. The top results show the average of each decision. So if the market requires the feature in 2010, this would be on average what the company makes in the entire architectural lifetime. All decisions except for prepare are a loss. Based on this, the company should choose to prepare.



	Exclude in all	Do nothing	Prepare	Include in all
Result	15.548-	3.246-	295	9.088-

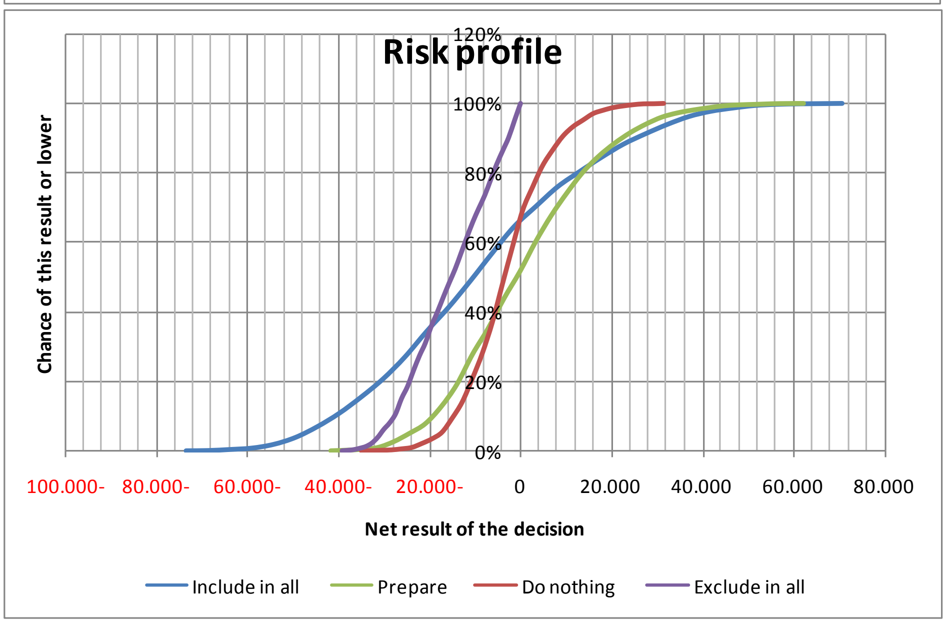
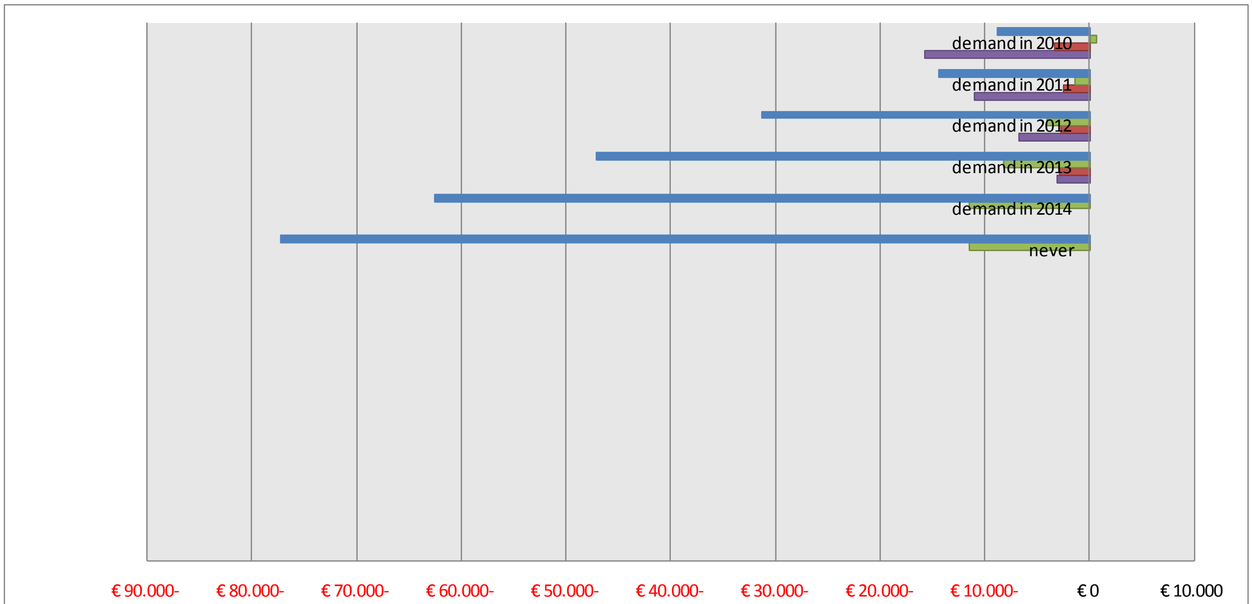


Exhibit 40 - Results of a fictive project

Averages give a good indication of the results, but say nothing about the risk. This is important because companies are usually not risk neutral. Therefore, the risk profile is given as well. In fact it is the Cumulative Density Function of the results for each of the four decisions. Each line shows the chance of having a specific result or less. For instance, prepare has about 50% chance of breaking even or making a loss, since that is the chance at making €0. However, for include this chance is 65%, for do nothing this is 70% and for exclude in all the chance is even a 100%! Again, one would favour the option prepare (green). Compared to do nothing (red), it is also expected to make more profit since the line lays more to the right. However the losses of prepare (green) are also bigger than in case of do nothing (red). So chances of making a profit are higher in case of prepare, but the losses are also bigger. Thus if a company really cannot afford to take on any loss, the option do nothing would probably be better. Even though the option prepare is expected to do better!

Once requested by participants, the results of all years were examined with a full simulation. This is depicted in Exhibit 41 for the fictive project.



								never	demand in 2014	demand in 2013	demand in 2012	demand in 2011	demand in 2010
Include in all	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 77.190-	€ 62.538-	€ 47.052-	€ 31.351-	€ 14.412-	€ 8.790-
Prepare	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 11.456-	€ 11.486-	€ 8.240-	€ 4.129-	€ 1.436-	€ 607
Do nothing	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 2.897-	€ 2.762-	€ 2.564-	€ 3.380-
Exclude in all	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 3.108-	€ 6.759-	€ 10.982-	€ 15.796-

Exhibit 41 - Results of all decisions in all years

The averages of all years give a good overview to see what happens if the demand is not in the expected year. If it is very likely that the feature will be demanded by 2010 or 2011, prepare is still the best choice. However if it is demanded by 2012, do nothing would have won and in case of no demand, the preparation might cost the company quite some money. If the company has strong indications that the feature will be demanded soon, or if they have some financial reserves, prepare would still be the best option. However, if this is not the case the company might choose to do nothing anyway. In short, averages tell quite a lot about the decisions. Therefore, they are good enough to scan over the years very quickly and see dominant effects. The risk profiles are useful to zoom in and make decisions. During the PM case this became very clear. Average give quite a good overview, so you really do not always need the risk profiles at the beginning.

The results for a single year can be simulated within seconds. Therefore, evaluating a single year was useful to see the effects of changes in input variables. The results of the most important year were also printed in a summary sheet that participants received at the end of the case. An example can be found in Appendix L. This way the participants could get an overview of the assumptions and results of their situation.

A summary of the method: answering Q3

The current section will answer central question 3, which is repeated below.

> Q3: How is the method shaped?

Up to now this chapter showed that a method was created that quantifies architectural investments based on options thinking. During the process feedback from Philips AppTech and external cases shaped the method to become as practical as possible. The four strategic decisions and standard relations in the model can map many architectural problems quite fast. Furthermore, the model is easily customizable when needed.

Does it work?: answering Q4

The last part of this chapter will answer the final central question 4. This is repeated below.

> Q4: Does the method meet the requirements?

To answer the question, the requirements are repeated from Chapter 3.

1. The framework should increase the willingness of participants to cooperate in creating product architecture
2. The framework should increase the financial insight according to participants
3. The framework should be practical

On all three points, there are indications that the method meets the requirements. On the aspect of cooperation, cases showed several times that participants want to use the results to stimulate discussion with others. People liked that the method shows architectural decisions in financial terms. It could help as an aid to stimulate discussion and also be valuable as a tool to convince others:

“But as is, this is already important. Because you can now start the discussion with the operations managers. Because he want everything at the highest possible level. He wants short throughput times, purchasing at a high level and only software keys to make the product customer specific. So he wants include in all.” [PM 412] concerning the results of decisions include in all and prepare.

“you cannot always predict the direction of the market and the competitor can always try to do different things. Well if that’s the case, you always have a loss because you cannot react since you should have made your architecture more flexible. For a marketeer, architecture is something costly because he does not gain from it. For him it’s just an investment which the customer does not see. This [the model] makes it visible that such an investment in fact does have an impact on the results .” [PM 593]

“Money is scarce and development gets a fixed budget. They need to make some smart choices about the things they do. And it could be – by the way I am convinced of it– that this helps to only choose for an option.” [PM 349]

On the aspect of financial insight, many liked the inclusion of uncertainty and choice. A key outcome was that the method showed that each decision has financial consequences and that there are multiple ways to react. Decisions do not have to be predetermined, they can be staged. This also became clear through the introduction material about which many were positive. The integration of the multiple decisions into one single method was a plus. It created some form of awareness that not deciding has an effect as well:

“We always tend to build in a lot of diversity. But if we just include everything… I now question if our desired diversity is always cheaper” [PM 311]

“Well an NPV calculation is in fact the same, but there it is: do it or do nothing. And this initiates to think about doing something in between. Not regarded as four independent scenarios, but as an integrated whole. That is for me the extra value. You could make three independent calculations, but this merges it into one input” [A2D 111]

As illustrated, the risks provide extra insight once a decision needs to be made. Many liked to see the uncertainty visualized in the risk profiles [PM 326]. Risk profiles show that there is still uncertainty in every investment:

“the number of alternatives to capture uncertainty is not very large. So that’s what might make this interesting.” [PM 131]

“What I do like is the thinking in distributions, which is omitted in NPV calculations. And that you also get a distribution of the profit instead of the point of a single holy number.” [A2D 116]

“And those distributions are good. Because, these decisions do not have a big difference and these are the ones to avoid. That’s a decision. And if the financial situation is good, you could invest now and if the financial situation is bad you choose to wait, because it probably will turn out OK” [A2D 128]

Regarding the practical use, the method turned out to be applicable and adaptable to all cases without much effort. In all three cases, people got used to inputting uncertainties quite fast. The cases could be inputted into the model fast through the help of the user interface and visual aids like graphs. Supported by somebody who is accustomed to the method, it took generally less than an hour model a case from an empty sheets to the first simulation results. Participant do need time to understand how their situation relates to the method and the majority of the time is spent on discussion, which should be seen as a valuable part of the process. Accordingly, the method is preferably used with the aid of a facilitator. Nevertheless, in general one can say that the method can be applied in a practical way and does not require extensive historical data or market research to start the discussion and obtain useful results.

Although the first results tend to be positive, one should be reluctant to make strong conclusions about the method, since it has not been applied at many cases. For now, the results are based on preliminary discussions and larger case studies would be useful. However, indications are promising that the method does aid in quantifying architectural decisions in a more practical way.

Chapter 6 Discussion

Achievements

Looking back at the project goal in Chapter 1, this method tried *to improve the joint creation of product architectures, by developing a practical method which quantifies the financial effects of choices in product architecture on multiple business functions*. The main discussion will be whether or not this succeeded. It is too soon to say if the method did improve the creation of architectures, but a practical method was created nevertheless through synthesising existing knowledge into a useful, integral approach. Theory of strategic product architecture was translated to a split in market behaviour and four architectural investment decisions. Some of them were staged because of managerial choice. Dominant effects like cost and time were included into the model and translated to the field of product architecture. The concept of choice and simulation is taken from option theory whilst the valuation itself is based on traditional discounting. The approach was constantly tested and improved to find the optimal balance between sophisticated methods that are virtually impossible to apply in daily life and practical ones that do not sufficiently account for reality. The result is a valuation which is not very hard to do, but still deals with uncertainty and choice in a reasonably accurate way. The method can include the most important financial effects regardless of in which business function it occurs. Furthermore, it has the flexibility to be adapted to specific situations. In short, the approach combines uncertainty, managerial choice, market behaviour and strategic architectural decisions in a practical way. Recall the knowledge gap identified by Jose et al.:

"today the methods for platform product development are not practical and future results can be obtained with an integral methodology using a practical design representation linked to an optimization methodology. Such methodology should link the most important costs, the economic savings and the design choices." (Jose, et al., 2005)

Up to a certain extent the method has integrated the latter in an integral and practical methodology and tried to fill this gap. Potentially elements of this method could be used to improve the research on this still complex matter.

Suggestions for further research

During the design process and case evaluations, some points emerged that could be interesting for further investigation. They are discussed briefly.

More user testing

Up from the start, the method was created with practical applicability in mind. As a result the method was constantly reviewed by consultants from Philips AppTech and tested in case applications. Although these applications show strong indications that the method can be useful, extensive user testing could aid to strengthen this indication. Therefore the method could be applied at more cases that are tested on the requirements. Furthermore, this could also open the door to future improvements.

Eliminating the black box fully

By creating a possibility to valuate architectures that were not valuated before, the method opened the financial black box of product architectures. The results can help to understand how costs and time to market can influence the results. As is common in many simulations, relations between variables are not always directly clear since a simulation run is needed to see the effects. This is especially the case when many variables are modelled and is one of the reasons why the method tried to limit the number of inputs. Graphs did aid in indentifying relationships, but this could be improved if participants see effects directly. Sensitivity analysis such as a tornado diagram could aid.

Adaption to other investment types

Although the four strategic decisions were based on applications in product architecture, a similar approach might be useful in other fields. Exhibit 20 (pp. 52) indicated how the four architectural decisions can be seen in a more abstract perspective. The method could be applied to other areas without having to change the mathematical principles at all. Probably only cosmetic modifications of the method would be needed to do this. This opens doors to many more applications that essentially have the same type of investment decisions very easily and could be an interesting topic for research.

Portfolio management

Since the method can assess architectural decisions fast, it could be possible to assess an entire product portfolio with the method. Due to time limitations the method has not been applied to an entire portfolio, although all cases indicated the relevance of product portfolio management. The possibilities of applying the method has been discussed with an expert on portfolio management and some initial possibilities were spotted. Finding the best portfolio strategy could be the optimization methodology mentioned by Jose that is currently not present in the method. Because the relevance of the topic a further investigation could be very worthwhile.

Interpreting results

Much of the value of the method came through the discussion that followed from the results. As stated in Chapter 5, none of the participants were interested in obtaining a single number or a single best decision. Instead, participants wanted to learn about the effects and uncertainties. This is one of the reasons why participants favoured the risk profiles. Accordingly, it would not be useful if the method would give a 'best' decision: it needs to give insight. However, the method may be improved even further if the process of obtaining this insight is investigated. This includes the decision making process as well. The investigation could help to know how decisions are made best and how the method could be adapted for this. Naturally, the method should never be seen as a replacement for decision making, but as an aid. Key is to adapt it in a way that the results aid decision making best.

Chapter 7 References

Baldwin C.Y. and Clark K.B. Design Rules: The Power Of Modularity [Book]. - Cambridge : MIT Press, 2000.

Baldwin C.Y. and Clark K.B. Managing in an age of modularity [Journal] // Harvard Business Review. - September-October 1997. - 5 : Vol. 75. - pp. 84-93.

Black F. and Scholes M. The Pricing of Options and Corporate Liabilities [Journal] // Journal of Political Economies. - 1973. - 3 : Vol. 81. - pp. 637-654.

Boer M. and Logendran R. A methodology for quantifying the effects of product development on cost and time [Journal] // IIE Transactions. - 1999. - Vol. 31. - pp. 365-378.

Borison A. Real Options Analysis: Where Are the Emperor's Clothes? [Journal] // Journal of Applied Corporate Finance. - 2005. - 2 : Vol. 17. - pp. 17-31.

Bowman C. and Ambrosini V. Tacit knowledge: Some suggestions for operationalization [Journal] // Journal of Management Studies. - 2001. - 6 : Vol. 38. - pp. 811-829.

Boyle P.P. Options: A Monte Carlo Approach [Journal] // Journal of Financial Economics. - 1977. - Vol. 4. - pp. 323-338.

Clark K.B. and Fujimoto T Product development performance [Book]. - Boston : Harvard Business School Pres, 1991.

Copeland T. and Tufano P. A Real-World Way to Manage Real Options [Journal] // Harvard Business Review. - March 2004. - pp. 90-99.

Copeland T., Koller T. and Murrin J. Valuation: Measuring and Managing the Value of Companies [Book]. - New York : John Wiley and Sons, 1994. - 2.

Copeland T.E. and Keenan P.T. Making real options real [Journal] // The McKinsey Quarterly. - 1998. - 3. - pp. 128-141.

Cox J.C., Ross S.A. and Rubinstein M. Option Pricing: A Simplified Approach [Journal] // Journal of Financial Economics. - 1979. - 3 : Vol. 7. - pp. 229-263.

Dai Z. and Scott M.J. Product platform design through sensitivity analysis and cluster analysis [Journal] // Journal of Intelligent Manufacturing. - 2007. - Vol. 18. - pp. 97-113. - DOI 10.1007/s10845-007-0011-2.

De Weerd-Nederhof P.C. [et al.] The Architecture Improvement Method: cost management and systemic learning about strategic product architectures [Journal] // R&D Managment. - November 2007. - 5 : Vol. 37. - pp. 425-439.

Eden C. Analyzing cognitive maps to help structure issues or problems [Journal] // European Journal of Operational Research. - [s.l.] : Elsevier B.V., 2004. - 159. - pp. 673-66.

Eden C. Cognitive mapping [Journal] // European Journal of Operational Research. - [s.l.] : Elsevier B.V., 1988. - 36. - pp. 1-13.

Fixon S.K Modularity and commonality research: past developments and future opportunities [Journal] // Concurrent Engineering. - [s.l.] : Sage Publications, 2007. - 2 : Vol. 15. - pp. 85-112. - 1063-293X.

Fixon S.K. A Roadmap for Product Architecture Costing [Book Section] // Product Platform and Product Familiy Design / book auth. Simpson T.W., Siddique Z. and Jiao J.R.. - [s.l.] : Springer US, 2006. - 978-0-387-25721-1.

Fixon S.K. Product architecture assesment: a tool to link product, process, and supply chain design decisions [Journal] // Journal of Operations Management. - [s.l.] : Elsevier B.V., 2005. - 23. - pp. 345-369.

Fujita K. and Yoshioka S. Optimal Design Methodology of Common Components for a Class of Products: It's Foundation and Promise [Conference] // ASME 2003 Design Engineering Technical Conferences and Computers and Information in Engineering Conference. - 2003.

Garud R., Kumaraswamy A. and Langlois R.N. Managing In The Modular Age [Book]. - Malden : Blackwell Publishers Ltd, 2003.

Gershenson J.K., Prasad G.J. and Zhang Y. Product modularity: definitions and benefits [Journal] // Journal of Engineering Design. - 2003. - 3 : Vol. 14. - pp. 295-313. - ISSN 0954-4828.

Gershenson J.K., Prasad G.J. and Zhang Y. Product modularity: measures and design methods [Journal] // Journal of Engineering Design. - 2004. - 1 : Vol. 15. - pp. 33-51. - ISSN 0954-4828.

Gil N. On the value of project safeguards: Embedding real options in complex products and systems [Journal] // Research Policy. - 2007. - Vol. 36. - pp. 980-999.

Gonzalez-Zugasti J.P., Otto K.N. and Baker J.D. Assesing value in platformed product family design [Journal] // Research Engineering Design. - 2001. - 13. - pp. 30-41.

Griffin A. and Hauser J.R. Integrating R&D and Marketing: A Review and Analysis of the Literature [Journal] // Journal of Product Innovation Management. - [s.l.] : Elsevier Science Inc., 1996. - Vol. 13. - pp. 191-215.

Guo F. and Gershenson J.K. Discovering relationships between modularity and cost [Journal] // Journal of Intelligent Manufacturing. - [s.l.] : Springer Science, April 2007. - 18. - pp. 143-157.

Henderson R.M and Clark K.B. Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms [Journal] // Administrative Science Quarterly. - [s.l.] : Johnson Graduate School of Management, March 1990. - 1 : Vol. 35. - pp. 9-30.

International Valuation Standards Committee International Valuation Standards [Book] = IVS. - 2003. - Sixth Edition.

Jiao J, Simpson T and Siddique Z Product familiy design and platform-based product development: a state-of-the-art review [Journal] // Journal of Intelligent Manufacturing. - [s.l.] : Springer Netherlands, 2007. - 18 : Vol. 2007. - pp. 5-29. - 0956-5515.

Jose A. and Tollenaere M. Modular and platform methods for product family design: literature analysis [Journal] // Journal of Intelligent Manufacturing. - 2005. - 16. - pp. 371-390.

Kasanen E., Lukka K. and Siitonen A. The Constructive Approach in Management Accounting Research [Journal] // Journal of Management Accounting Research. - 1993. - Vol. 5. - pp. 243-264.

Kaul A. and Rao V.R. Research for product positioning and design decisions: An integrative review [Journal] // International Journal of Research in Marketing. - 1995. - Vol. 12. - pp. 293-320.

Krishnan V. and Ulrich K.T Product Development Decisions: A Review of the Literature [Journal] // Management Science. - 1 2001. - 1 : Vol. 47. - pp. 1-21.

Lau Antonio K.W., Yam R.C.M. and Tang E. The impacts of product modularity on competitive capabilities and performance: An empirical study [Journal] // International Journal of Production Economics. - 2007. - 105. - pp. 1-20.

Layer A. [et al.] Recent and future trends in cost estimation [Journal] // International Journal of Computer Integrated Manufacturing. - 2002. - 6 : Vol. 15. - pp. 499-510.

Lint O. and Pennings E. An option approach to the new product developent process: a case study at Philips Electronics [Journal] // R&D Management. - [s.l.] : Blackwell Publishers, 2001. - 2 : Vol. 31. - pp. 163-172.

Luehrman T.A. Investment Opportunities as Real Options: Getting Started on the Numbers [Journal] // Harvard Business Review. - July-August 1998. - pp. 51-67.

Mikkola J.H. and Gassmann O. Managing Modularity of Product Architectures: Toward an Integrated Theory [Journal] // IEEE Transactions On Engineering Management. - 2003. - 2 : Vol. 50. - pp. 204-218.

Mikkola J.H. Management of Product Architecture Modularity for Mass Customization: Modeling and Theoretical Considerations [Journal] // IEEE Transactions on Engineering Management. - 2007. - 1 : Vol. 54. - pp. 57-69.

Morris C.R. and Ferguson C.H. How Architeture Wins Technology Wars [Journal] // Harvard Business Review. - March-April 1993. - pp. 86-96.

Myers S.C. Determinants of corporate borrowing [Journal] // Journal of Financial Economics. - 1977. - Vol. 5. - pp. 147-175.

Peter Boer F. Risk-adjusted valuation of R & D projects [Journal] // Research Technology Management. - 2003.

Peter Boer F. Traps, pitfalls and snares in the valuation of technology [Journal] // Research Technology Management. - 1998. - 5 : Vol. 41. - pp. 45-54.

Pil F.K. and Cohen S.K. Modularity: Implications For Imitation, Innovation, And Sustained Advantage [Journal] // Academy of Management Review. - 2006. - 4 : Vol. 31. - pp. 995–1011.

Pimmler T.U. and Eppinger S.D. Integration analysis of product decompositions [Conference] // Proceedings of the 1994 ASME Design Engineering Technical Conferences. - 1994.

Rodrigues A. and Armada M.J.R. The valuation of modular projects: A real options approach to the value of splitting [Journal] // Global Finance Journal. - 2007. - Vol. 18. - pp. 205-227.

Rothwell R. [et al.] Sappho updated - project sappho phase II [Journal] // Research Policy. - 1974. - 3. - pp. 258-291.

Samuelson P.A. Rational theory of warrant pricing [Journal] // Industrial Management Review. - 1965. - 6. - pp. 13-31.

Sanchez R and Collins P Competing -and Learning- in Modular Markets [Journal] // Long Range Planning. - [s.l.] : Elsevier Science Ltd., December 2001. - 6 : Vol. 34. - pp. 645-667.

Sanchez R. Modular architectures, knowledge assets and organizational learning: new management processes for product creation [Journal] // International Journal of Technology Management. - 2000. - 6 : Vol. 19. - pp. 610-629.

Sanchez R. Strategic Product Creation: Managing New Interactions of Technology, Markets and Organizations [Journal] // European Management Journal. - 1996. - 2 : Vol. 14. - pp. 121-138.

Sharman D.M and Yassine A.A. Architectural Valuation using the Design Structure Matrix and Real Options Theory [Journal] // Concurrent Engineering. - June 2007. - 2 : Vol. 15. - pp. 157-173.

Siddique Z. and Repphun B. Estimating Cost Savings when Implementing a Product [Journal] // Concurrent Engineering. - 2001. - 4 : Vol. 9. - pp. 285-294.

Simon H.A. The architecture of complexity [Conference] // Proceedings of the American Philosophical Society. - 1962. - Vol. 106. - pp. 467-482.

Slater S.F., Reddy V.K. and Zwirlein T.J. Evaluating Strategic Investments Complementing Discounted Cash Flow Analysis with Options Analysis [Journal] // Industrial Marketing Management. - 1998. - 5 : Vol. 27. - pp. 447-458.

Suh E.S., De Weck O.L. and Chang D. Flexible product platforms: framework and case study [Journal] // Research in Engineering Design. - 2007. - 18. - pp. 67-89. - DOI 10.1007/s00163-007-0032-z.

Teuns S The next step in product architecture improvement [Report] : Masters thesis. - Eindhoven : Philips Applied Technologies, 2005.

Thevenot H.J. [et al.] An Index-based Method to Manage the Tradeoff between Diversity and Commonality during Product Family Design [Journal] // Concurrent Engineering. - June 2007. - 2 : Vol. 15. - pp. 127-139.

Ulrich K. The role of product architecture in the manufacturing firm [Journal] // Research Policy. - [s.l.] : Elsevier, 1995. - 24. - pp. 419-440.

Ulrich K.T. and Eppinger S.D. Product Design And Development [Book]. - New York : McGraw-Hill, 2000.

Van Wie M.J. [et al.] Interfaces and product architecture [Conference] // ASME design engineering technical conferences. - Pittsburg, PA : [s.n.], 2001. - DETC01/DTM-21689.

Verschuren P. and Doorewaard H. Het ontwerpen van een onderzoek [Book]. - Den Haag : Lemma, 2007. - 4e druk. - ISBN 978-90-5931-496-2.

Winston W.L. Operations Research: Applications and Algorithms [Book]. - Belmont : Brooks/Cole - Thomson Learning, 2004. - Fourth International Student Edition. - ISBN 0-534-42362-0.

Yassine A.A. and Wissman L.A. The Implications of Product Architecture on the Firm [Journal] // Systems Engineering. - 2007. - 2 : Vol. 10. - pp. 118-137.

Zwerink R [et al.] Cost management and cross-functional communication through product architectures [Journal] // R&D Management. - 2007. - 1 : Vol. 37.

Royal Philips

Strategic Architecture Valuation: Appendices

Public version

Mark Workum
15-12-2008

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Appendix A The mechanisms of Net Present Value

Net present value is the most commonly used technique to value investments. It determines the value that a project has to a firm, expressed in money in the present. The underlying principle is that using money costs money each year. Thus in order for a project to add any value to a company it should at least generate the this cost of money, i.e. the discount rate.

To illustrate this concept, take a cost of money of 5%. This means that if the company has €100 to invest, it should pay 5% per year for the use of this money. Thus if a company would now borrow €100 and invest it, it should at least make €100*1,05 = €105 in the future in order to exactly pay for the cost of money. Thus €105 one year in the future is only worth €100 now. Stated otherwise, money in the future is worth less than the same money now. This is called the time value of money.

The Net Present Value approach enables the comparison of projects by expressing the cash flows in money in the present. It consists of three steps:

1. Determine all future cash flows of an investment
2. Discount the cash flows to the present with the discount rate
3. Decide about the project:
    a. Accept the project if the discounted cash flow is positive
    b. Reject the project if the discounted cash flow is negative or zero

The workings will be explained using an example. Step one indicates that all cash flows should be determined. The cash flow diagram of a fictive project is stated in Exhibit 1. If all cash flows are summed up directly, the project would seem to be profitable for the company, since in the end a €25 profit would be made. However the cost of money is not accounted for, which is the next step in an NPV calculation.

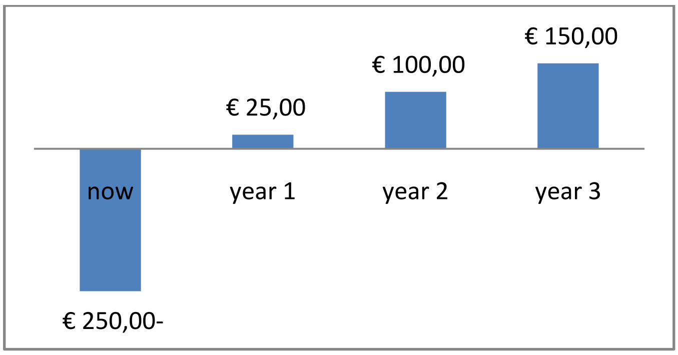


Exhibit 1- Cash flow diagram of a fictive project

Step 2 indicates that the cash flows should be discounted to the present to account for the cost of money. This is called the present value and is determined using Equation 1.

$$PV = CF_{future} * discount\ factor = \frac{CF_{future}}{(1+r)^n}$$

Equation 1

In this equation PV is the present value, CF_{future} is the cash flow in the future, r is the discount rate and n is the number of years in the future. A discount rate of 10% is used for illustration, which leads to the present value. The present values are calculated in Exhibit 2. Now it becomes clear that money further away in the future is worth less now. For instance, €150 three years from now, is only worth €112,70 in the present.

	Cash flow	Discount factor	Present value
now	€ 250,00-	1	€ 250,00-
year 1	€ 25,00	0,9091	€ 22,73
year 2	€ 100,00	0,8264	€ 82,64
year 3	€ 150,00	0,7513	€ 112,70
total	€ 25,00		€ 31,93-

Exhibit 2- Net Present Value calculation of a fictive project

Since the present values of the cash flows are calculated, the Net Present Value is simply the sum of these values. Thus the added value to a company would be minus €31,93. Accordingly step 3 now indicates that the investment should be rejected, since a negative value is added to the firm if the cost of money is accounted for. This conclusion is the opposite of summing the cash flows without discounting.

One of the problems in making a good NPV calculation is determining the right discount rate. Usually companies use the Weighted Average Cost of Capital (WACC) as their discount rate. This factor is determined by averaging the interest rates that the different sources of the money of a company require. To be more exact, part of the money of a company is funded by loans which have a predetermined interest rate. Another part of the money is owned by shareholders. They usually require a higher interest rate, since they have more risk than in case of a loan. These different interest rates then need to be averaged according to the capital distribution of a company to determine the average cost of money rate. Accordingly, projects that beat this WACC rate, generate more money than the money costs on average. Therefore they add value to the firm.

A different approach to determine the discount rate is to set it to the average return of project of a company. Projects will then only be accepted if they are at least as profitable as the average other project. This emphasises the scarcity of money. Another commonly used practice is to higher the discount rate for riskier projects, known as a risk premium. After all, for two projects with identical cash flows an investor would prefer the project with the lowest amount of risk, thus requiring more return on investment for a project with more risk. Several similar ways of adjusting the discount rate can be determined, however a more detailed discussion about the discount rate falls out of the scope of this study. The central notion though is that the discount rate should equal the real cost of money of a specific project if it is funded by the market. Thus if a project is to be funded one should find an existing project with similar characteristics in terms of risk and expected profit. The way that project is funded then resembles a correct cost of money, i.e. a market equivalent cost of money.

Appendix B The mechanisms of Option theory

The call option explained

In the financial world, a call option is the right –not an obligation– to buy an amount of stocks (called the underlying asset) in the future (the expiration time) at a predetermined price (the strike price). Options that are valid before and at the expiration date are termed American call options. These options are most commonly used. However some options are only valid at the expiration date itself and are termed European call options.

As an example, let's assume it is August 2008. Currently Philips is €21 on the stock market. At this time you could have a call option Philips, December 2008, €25. This gives you the right to buy 100 shares of Philips (underlying asset) at a price of €25 (strike price) each before the third Saturday of December 2008 (expiration date). Currently it would be foolish to use that right, i.e. exercising the call option. After all, why buy a stock for €25 if you could buy it on the market for €21? However if Philips is worth €27 at December 2008, it will be smart to exercise the option. After all, you could buy the stock for €25 and sell it for €27, giving a €2 profit per stock.

Unfortunately you do not get this right for free. Another person has to sell the stocks to you at €25 if you exercise your right. For this you pay him. For instance, you can buy the call option in the example for €0,40 in August 2008. This money goes to the person who sells (also called writes) the call option, i.e. who is taking on the obligation to sell the stock at €25. The price of the option is determined by the market, since the options can be traded. A payoff scheme of this call option is depicted in Exhibit 3. The horizontal axis has the price of the underlying asset (Philips in this case) on the expiration date. On the vertical axis the profit for the call option buyer is plotted.

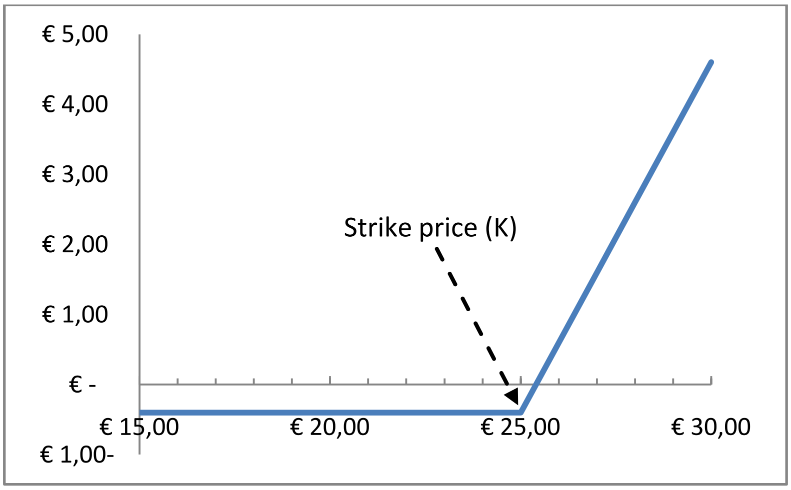


Exhibit 3 – Payoff scheme of a call option

So a buyer of the call option will have a loss of €0,40 if Philips remains at the strike price (usually mathematically denoted as K) of €25 or lower. At €25,40 the buyer will break even and above this level, the buyer makes a profit.

The value of a call option. The principle of no arbitrage

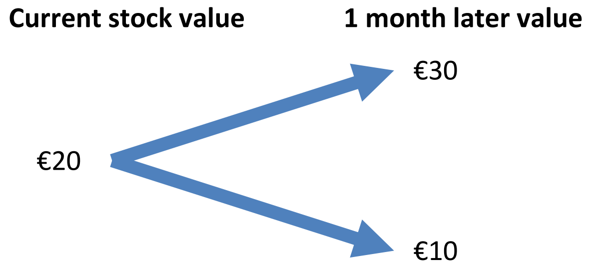
As stated before, the call options (the right to buy or obligation to sell) themselves are traded on the financial market. Therefore a price for a call option is established. The question now arises how much an option is worth, i.e. to determine its value. If you look at an option more closely, it is a kind of investment. In the example you can invest €0,40 and for this you have a possible return in the future. Off course your chances on having returns may depend on the type of underlying asset. Shares that have a big chance to end below the strike price, have considerable more risk than those stocks that will go sky high. The traditional NPV/DTA approach would be to estimate some possible stock outcomes and their probabilities, e.g. see (Samuelson, 1965). These outcomes should then be discounted to the present using an appropriate cost of capital: a bit higher for risky options and lower for safe options. However, everybody assesses different probabilities and risks. Accordingly, this price does not resemble the option prices on the stock market at all!

Option theory uses a concept to value options that is totally different from the traditional NPV/DTA concept. This theory does resemble correct prices on the option markets because it is based on the assumption of no arbitrage, which seems to be a driving force in the financial markets.

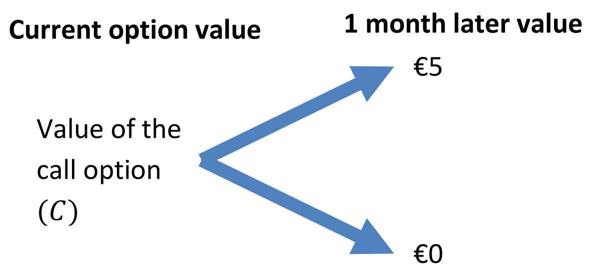
Option theory is based on the assumption of no arbitrage

The no arbitrage assumption means that in a fully transparent market (like the options market) ***it is impossible to make a construction*** with options and stocks ***that requires no investment but makes a guaranteed profit***. Some financial analysts say *there ain't no such thing as a free lunch*. As recalled, an option is not free since you could earn money without having to invest a single euro. That's why you pay a price for the option. However it will be demonstrated that it is always possible to make a guaranteed profit, if the option price does not reach a specific value. This possibility to make free profit is called arbitrage. A free market is full of these opportunity seekers, called arbitrageurs. Because they are constant looking for a free profit, the options that deviate from the no arbitrage value will converge to it very fast. This is why the values from option theory usually resemble the market very accurately. Arbitrage and option value will now be demonstrated.

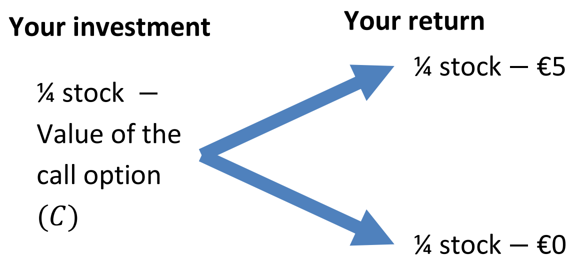
Suppose a stock of Philips is now worth €20. For simplification let's assume that in the next month there are only two possible stock prices, €30 and €10.



We now want to know what a call option for €25 is worth now. If the price goes to €30, the call will be exercised and will be worth it's profit of $€30 - €25 = €5$. However, if the price goes to €10, the call will not be exercised and the call will be worth €0. After all, nobody will buy a share for €25 if they can buy it for €10 at the stock market.



Now assume you buy ¼ share of Philips and write a call. This means you make an investment of ¼ stock, minus the money you **get** from the call option. For getting this money, you take on the obligation to deliver a stock of Philips for the price of €25.



If the stock goes to €30, you still own the ¼ stock but need to deliver 1 stock for €25 that you can buy for €30. Thus you make a loss of €5 on writing the call. Therefore your return is the following.

$$return_{up} = \frac{1}{4} stock - loss\ of\ the\ option = \frac{1}{4} * €30 - €5 = €7{,}50 - €5 = €2{,}50$$

Now assume the stock goes down to €10. You still own ¼ stock, but will not have any loss on the call option. Therefore your return is the following

$$return_{down} = \frac{1}{4} stock - loss\ of\ the\ option = \frac{1}{4} * €10 - €0 = €2{,}50$$

Your investment

Your return

¼ stock −
Value of the
call option
(C)

$€7{,}5 - €5 = €2{,}50$

$€2{,}50 - €0 = €2{,}50$

This conclusion is interesting. Whatever happens to the stock price, you make a return of €2,50 one month from now. Since this return is guaranteed, there is no risk involved in this investment. Therefore the €2,50 can be discounted to the current time using a low risk free interest, such as 5% per year.

$$\frac{€2{,}50}{1{,}05^{1/12}} = €2{,}49$$

This present value of the return should be equal to the investment. Thus

$$¼\ stock - Value\ of\ the\ call\ option\ (C) = €2{,}49$$

$$Value\ of\ the\ call\ option\ (C) = ¼\ stock - €2{,}49$$

$$Value\ of\ the\ call\ option\ (C) = ¼\ €20 - €2{,}49 = €5 - €2{,}49 = €2{,}51$$

This price of €2,51 is the price of the call under no arbitrage conditions. To illustrate the principle of arbitrage, let's see what happens if the price of the option with a strike price of €25 is not equal to this no arbitrage price, such as €3. You can now make money without investing a single euro, by buying the exact amount of stocks under non arbitrage conditions and writing the call and receiving €3. In the example the amount of stock was ¼.

Your investment

Your return in present value

$$¼\ stock - Value\ of\ the$$

$$call\ option\ (C) =$$

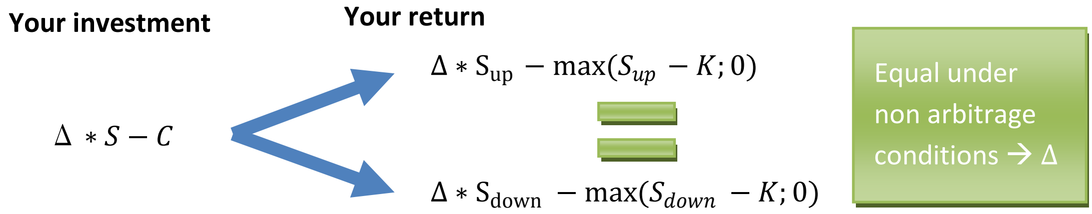
$$¼ * €20 - €3 = €2$$

$$\frac{¼\ €30 - €5}{1{,}05^{1/12}} = \frac{€2{,}50}{1{,}05^{1/12}} = €2{,}49$$

$$\frac{¼\ €10 - €0}{1{,}05^{1/12}} = \frac{€2{,}50}{1{,}05^{1/12}} = €2{,}49$$

As you can see, you can get a guaranteed profit of $€2{,}49 - €2 = €0{,}49$ once the option price deviates from its non arbitrage value. Do this a couple of times and you're a millionaire for free. Since this is exactly what every arbitrageur tries to achieve, deviating option values will return to the non arbitrage value very fast.

In the example the amount of stock that one should buy to always get a guaranteed return of €2,50 was given as ¼. This number is called the hedge ratio and is often denoted as Δ. The hedge ratio Δ is determined setting by equalling the returns in the up state and the down state as stated in Equation 2.



Rearranging the equation gives Equation 3. Finally, just as in the example, the future return is discounted using the risk free interest rate and should equal the initial investment using Equation 4. Rearranging gives the no arbitrage value of the call option C in Equation 5. Although the math may look intimidating, it is exactly what was done during the example.

$$\Delta * \mathrm{S}_{\mathrm{up}} - \max(S_{up} - K; 0) = \Delta * \mathrm{S}_{\mathrm{down}} - \max(S_{down} - K; 0)$$

Equation 2

$$\Delta = \frac{\max(S_{down} - K; 0) - \max(S_{up} - K; 0)}{S_{down} - S_{up}}$$

Equation 3

$$\Delta * S - C = \frac{\Delta * \mathrm{S}_{\mathrm{up}} - \max(S_{up} - K; 0)}{(1+\mathrm{r})^{\mathrm{t}}}$$

Equation 4

$$C = \Delta * S - \frac{\Delta * \mathrm{S}_{\mathrm{up}} - \max(S_{up} - K; 0)}{(1+\mathrm{r})^{\mathrm{t}}}$$

Equation 5

Δ: Hedge ratio

S: Current stock price

S_{up} : Stock price in the up state

S_{down} : Stock price in the down state

K: Strike price of the option

C: Value of the option

r: Risk free interest rate per year

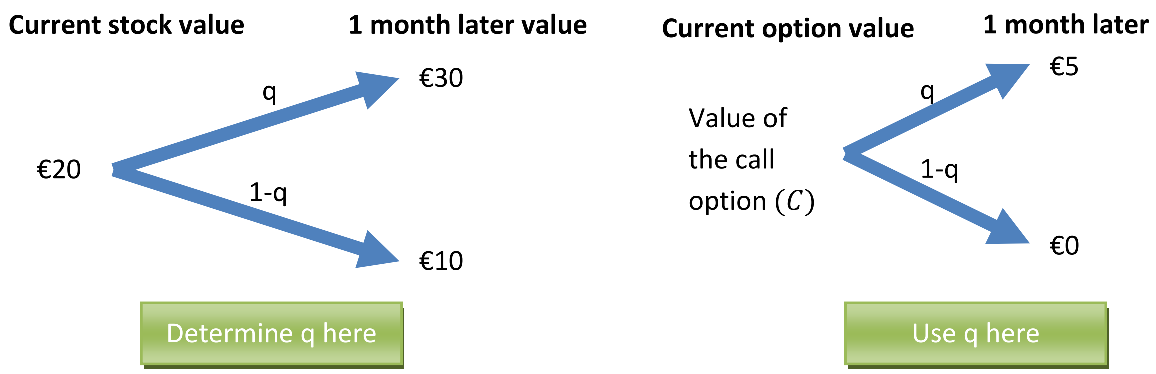
t: Time period in years

An important characteristic about option theory is that the market value of an option is only determined by knowing the future prices of the stock and the risk free cost of money. Contrary to an NPV or a DTA, no probabilities nor a market equivalent cost of money need to be estimated to correctly determine the market value of an option. Instead, the assumption of no arbitrage is used.

The same valuation using risk neutral probabilities

Although an understanding of the hedge ratio Δ is needed to understand arbitrage, there is another technique to get obtain the same no arbitrage option value C. This approach is called risk neutrality and was first described by (Cox, Ross, & Rubinstein, 1979). The mechanics of the risk neutral probabilities are easy to describe. However, the argumentation that it equals the previous method with hedging ratio Δ is not trivial and falls outside the scope of this study[1]. The method basically says that the price of an option can be determined using the non arbitrage principle by simply taking the expected value of the option values and discounting it with the risk free rate. This is similar to an uncertainty node in a decision tree analysis. However this only holds if very specific probabilities are used, called risk neutral probabilities.

Risk neutral probabilities are only determined by the value of the underlying asset. The same example will be used again. The stock is now worth €20 and can be either €10 or €30 one month from now. The call at the strike price $K = €25$ will then be worth either €5 or €0. The risk free discount rate $r = 5\%$ per year.



Now let's find those specific risk neutral probabilities q. These are based only on the values of the underlying asset and are given by the equation below.

$$S(1+r)^t = qS_{up} + (1-q)S_{down}$$

The example gives the following solution for q (figures are rounded for clarity).

$$20 * 1{,}05^{1/12} = 30q + (1-q)10$$
$$20{,}08 = 30q - 10q + 10$$
$$10{,}08 = 20q$$
$$q = 0{,}504$$

The value of the call can now be determined by using these risk neutral probabilities and discounting with the risk free rate. The equation below can be used.

[1] Readers who are interested in the argumentation are referred to the first sections of (Cox, et al., 1979)

$$C(1+r)^t = q * \max(S_{up} - K; 0) + (1-q) * \max(S_{down} - K; 0)$$

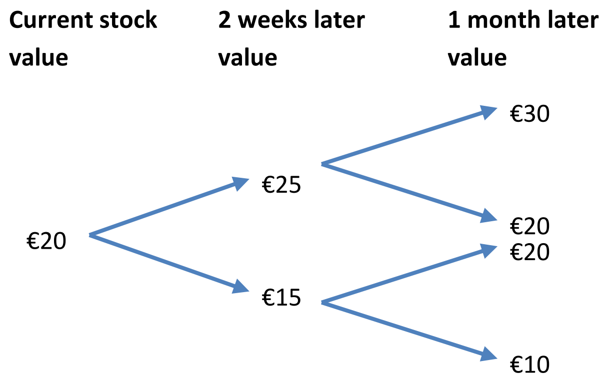
The example gives the following answer.

$$C * 1{,}05^{1/12} = q * 5 + (1-q) * 0$$
$$C * 1{,}05^{1/12} = 0{,}504 * 5$$
$$C = \frac{0{,}504 * 5}{1{,}05^{1/12}} = 2{,}51$$

This value equals the value found with using the hedge ratio Δ.

Multiple periods to create a detailed price movement

In the example only a two way movement of the price for the time interval of a month was evaluated. However one can add multiple periods together to model a more detailed price movement. For instance, two periods of two weeks can be added to get a detailed price movement of a month.



The top and bottom branches at the end can now be valued just like an ordinary call option with the delta hedging method. Again, we assume that you make an investment of buying Δ shares and writing one call option. This means that you receive the value of the call C. Again, your return will be the value of your amount of Δ shares minus the value of the call. After all, recall that have the obligation to deliver a stock at the strike price $K = €25$. Nothing new so far. Evaluating the top branch and bottom branch gives two values of the call.

	Your investment	Your return	
		$\Delta * €30 - €5$	$\Delta = 0{,}5$
Top branch:	$\Delta * €25 - C$		$C = €2{,}52$
		$\Delta * €20 - €0$	

		$\Delta * €20 - €0$	$\Delta = 0$
Bottom branch:	$\Delta * €15 - C$		$C = €0$
		$\Delta * €10 - €0$	

$$r = 5\%\ per\ year$$

Now the starting branch can be evaluated. However, at this point the value of the call is the value which is calculated previously. Thus, $\max(S_{up} - K; 0)$ is replaced by C_{up} and $\max(S_{down} - K; 0)$ is replaced by C_{down} .

	Your investment	Your return	
		$\Delta * €25 - €2{,}52$	$\Delta = 0{,}252$
Start branch:	$\Delta * €20 - C$		$C = €1{,}27$
		$\Delta * €15 - €0$	

$$r = 5\%\ per\ year$$

This gives a call value of $C = €1{,}27$. Naturally the same value can be found by using risk neutral probabilities.

The Geometric Brownian Motion

So far we discussed extensively how options can be valuated assuming the principle of non arbitrage. In the example some fixed values of future asset prices were stated. However in reality these are not known. Therefore historical data of stock prices are used to estimate the future price behaviour of stocks. Often people assume stocks to behave with a Geometric Brownian Motion (GBM). This will be explained first.

The GBM is a price behaviour that assumes that every period of time, prices rise with a drift μ and fluctuate with a normal distribution. It is described by the following differential equation, which is statd without proof.

$$dS_t = \mu S_t dt + \sigma S_t\ N(0{,}1)\sqrt{dt}$$

The variables in this equation are defined as follows.

S_t	Stock price at time t		σ	Volatility of the stock
μ	The drift of the stock. Interpret this as the trend which the prices are following.		$N(0,1)$	Standard normal distribution with mean 0 and standard deviation of 1
t	The time			

To understand this behaviour, we will use an example. The differential equation will be rewritten to a finite example, by replacing d by Δ.

$$\Delta S_t = \mu S_t \, \Delta t + \sigma S_t N(0,1)\sqrt{\Delta t}$$

This equation is the same as

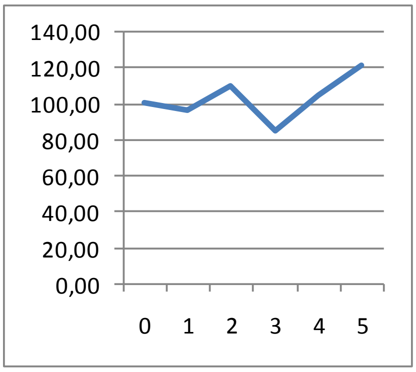
$$S_{t+\Delta t} = S_t + \mu S_t \, \Delta t + \sigma S_t N(0,1)\sqrt{\Delta t}$$

Let's assume that Δt equals one day. Then in words the equation states this:

$$Price\ tomorrow = Price\ today + Part\ of\ the\ price\ today + A\ random\ fluctuation$$

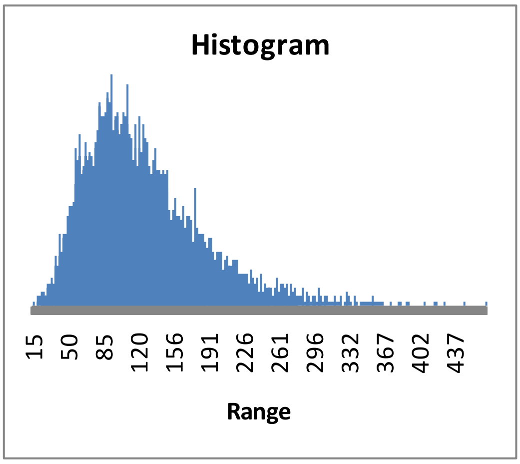
The drift μ determines how much the a part of the price today needs to be added (or subtracted if μ is negative). The random fluctuation can be seen as a random shift upwards or downwards. After all, the fluctuation is a standard normal distribution. The volatility σ determines the size of the fluctuation. Stock market analysis determine both of these parameters from historical data. Exhibit XX gives an example of a GBM and plots the points in a graph.

t	S_t (1)	$\mu S_t\, \Delta t$ (2)	$N(0,1)$	$\sigma S_t N(0,1)\sqrt{\Delta t}$ (3)	S_{t+1}
0	100,00	4,00	-0,37	-7,38	96,62
1	96,62	3,86	0,51	9,77	110,26
2	110,26	4,41	-1,35	-29,73	84,93
3	84,93	3,40	0,96	16,28	104,61
4	104,61	4,18	0,59	12,43	121,23
5	121,23				
	$\mu = 0{,}04$		In all cases $\Delta t = 1$		
	$\sigma = 0{,}2$		N(0,1) is just a random sample		



An important aspect of the GBM, is that its values have a lognormal distribution. This is illustrated for the example the figure below[2].

[2] The histogram is based on 10000 samples of a GBM with drift $\mu = 0{,}04$ and volatility $\sigma = 0{,}2$ on $t = 5$, with increments of $\Delta t = 1$



The GBM to determine the price of an option

When stock market analysts want to determine the price of an option, they often assume a GBM with volatility σ and drift δ. These parameters are derived from historical data. With the modelled GBM, three methods can be used to determine the option value. These are a binominal lattice, the Black-Scholes formula and a Monte Carlo simulation. The techniques are discussed briefly.

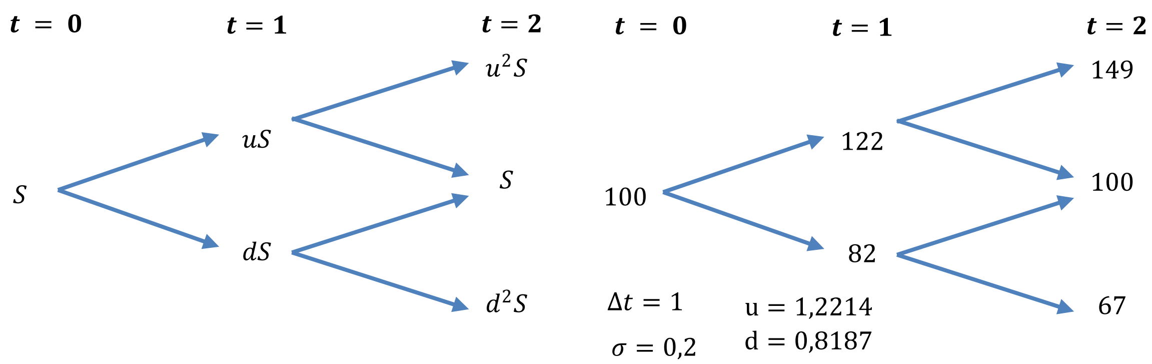
The GBM in a binominal lattice

A binominal lattice is a tree structure. However, the values are now based on the volatility parameter σ from the GBM that was based on historical data. The drift μ is not needed. A binominal lattice starts with stock value S. In the following period, the stock price can either be in the upstate with a value uS or in the downstate, with value dS. The factors u and d are purely based on the volatility σ and the time between two periods Δt. The formulae are stated without proof. The interested reader is referred to (Cox, Ross, & Rubinstein, 1979).

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = \frac{1}{u}$$

The binominal lattice now looks like the figure below.



Option values can now be calculated using a hedge ratio Δ or risk neutral probabilities as demonstrated above, both requiring the risk free rate r.

The GBM in the Black-Scholes formula

The price of a European call option can be calculated directly by the Black-Scholes differential equation (Black & Scholes, 1973). The equation assumes a GBM and the non arbitrage principle. Again it is stated without proof.

$$C = S\Phi(d_1) - Ke^{-rT}\Phi(d_2)$$

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$$\text{in which } \Phi \text{ is the standard normal cumulative distribution function (CDF)}$$

$$\Phi(d_n) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{d_n} e^{-\frac{x^2}{2}}dx$$

Note that this equation only requires the volatility σ from the GBM and the risk free rate r. However the option value is not dependant of the drift μ.

The GBM in a Monte Carlo simulation

A Monte Carlo simulation is the final, most commonly used method to determine the option price. It simply simulates many stock paths up to the expiration time T. Then at the end the option value can be determined by simply using the already addressed rule of options thinking: $\max(S_T - K; 0)$. After all, if the stock price S_T at expiration time is higher than the strike price K, people will use their right to buy the stock at price K, i.e. exercise the option. If S_T is lower, the call option is worthless. The first assumption of the underlying stock price is again the GBM. Therefore the simulation will model many paths of this equation.

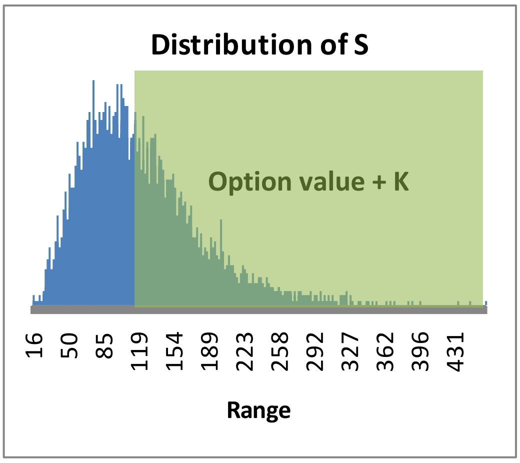
Recall that the second assumption in option theory is that of no arbitrage. One of the consequences of this assumption is that risk neutral probabilities lead to a correct option value (Cox, Ross, & Rubinstein, 1979). Therefore, the drift μ is replaced by the risk free rate r in the GBM. (Boyle, 1977). This gives the following GBM to determine option prices (only μ is replaced by r):

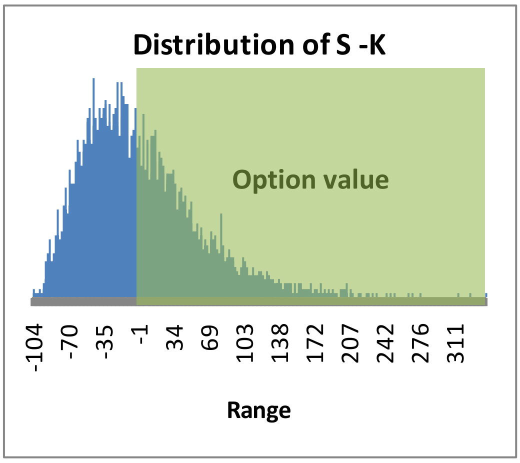
$$dS_t = rS_t dt + \sigma S_t\, N(0,1)\sqrt{dt}$$

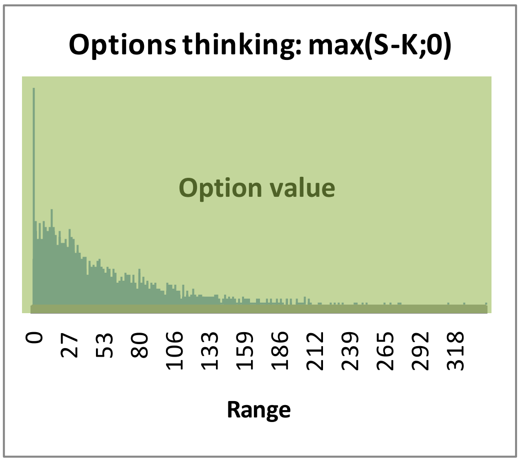
Please note that the option value again is independent of the drift μ. The table below shows an example of a Monte Carlo simulation to calculate the option value. A simulation of 5 risk neutral GBM paths is made. The option value is calculated and the average is taken. Finally this value is discounted with the risk free interest rate. Note that the answer of this example is wrong. In reality the option is worth 16,39 instead of 5,60. This is not because of the method, but because of the low number of simulation runs. In order to get a better approximation, the number of integrations should have a size of hundreds of thousands instead of 5.

n	S_0	S_1	S_2	S_3	S_4	S_5	$\max(S_5 - K;0)$
1	100,00	89,99	95,70	96,38	125,67	152,34	32,34
2	100,00	97,86	111,85	89,63	91,59	123,37	3,37
3	100,00	73,16	76,56	90,83	90,60	41,10	0
4	100,00	94,25	92,68	148,28	159,34	93,52	0
5	100,00	112,78	88,06	93,15	93,20	70,31	0
	$r = 0{,}03$		$K = 120$			average	7,14
	$\sigma = 0{,}2$		$T = 5$			PV average	5,60

Recall that the prices of a GBM are distributed lognormal. Since the option will only be exercised above the strike price K, the option value is just simply average stock price S_5 minus K above the exercise price K. Notice that this average is represented by the area above K in the probability distribution. This is also represented by the entire area of the distribution of the profit after options thinking $\max(S - K; 0)$ which is illustrated in the last histogram.







The realization that the option value is simply the average of many possible stock prices above the strike price K will be important for the construction of a new method. The special thing that makes the calculation of the option prices correct is the use of a risk neutral GBM.

Appendix C Details of the case evaluations

The current section describes how the framework will be tested. The case evaluation was initially meant to test the method on its requirement. However, due to time limitations it was not possible to obtain enough participants for a valid study. Accordingly, the results from the case study is used as feedback for the method, but not to make conclusions that can be generalized.

Goal formulation

The purpose of this stated below. A definition of key concepts is given as well.

To determine the value of the method to real life cases

Value: Value is defined as the ability of the new framework to positively influence the joint creation of product architectures

Joint creation [repeated from the project introduction]: Joint creation is defined as the creation of a product architecture by multiple business functions whilst taking their requirements and interests into consideration

Construct definition

The project requirements form the basis to answer this question. These requirements are repeated below.

1. The framework should increase the willingness of participants to cooperate in creating product architecture
2. The framework should increase the financial insight according to participants
3. The framework should be practical

In order to create constructs the requirements are defined below.

Practical: The practical use is defined as the ability of the new framework to be directly applicable to real life cases encountered by practitioners in product architecture

Cooperation willingness: The cooperation willingness is defined as the ability of the new framework to stimulate the willingness of business functions to jointly create product architectures

Financial insight: Financial insight is defined as the ability of the new framework to influence the perceived understanding by business functions of the financial effects that decisions in product architecture have on a company

Research strategy

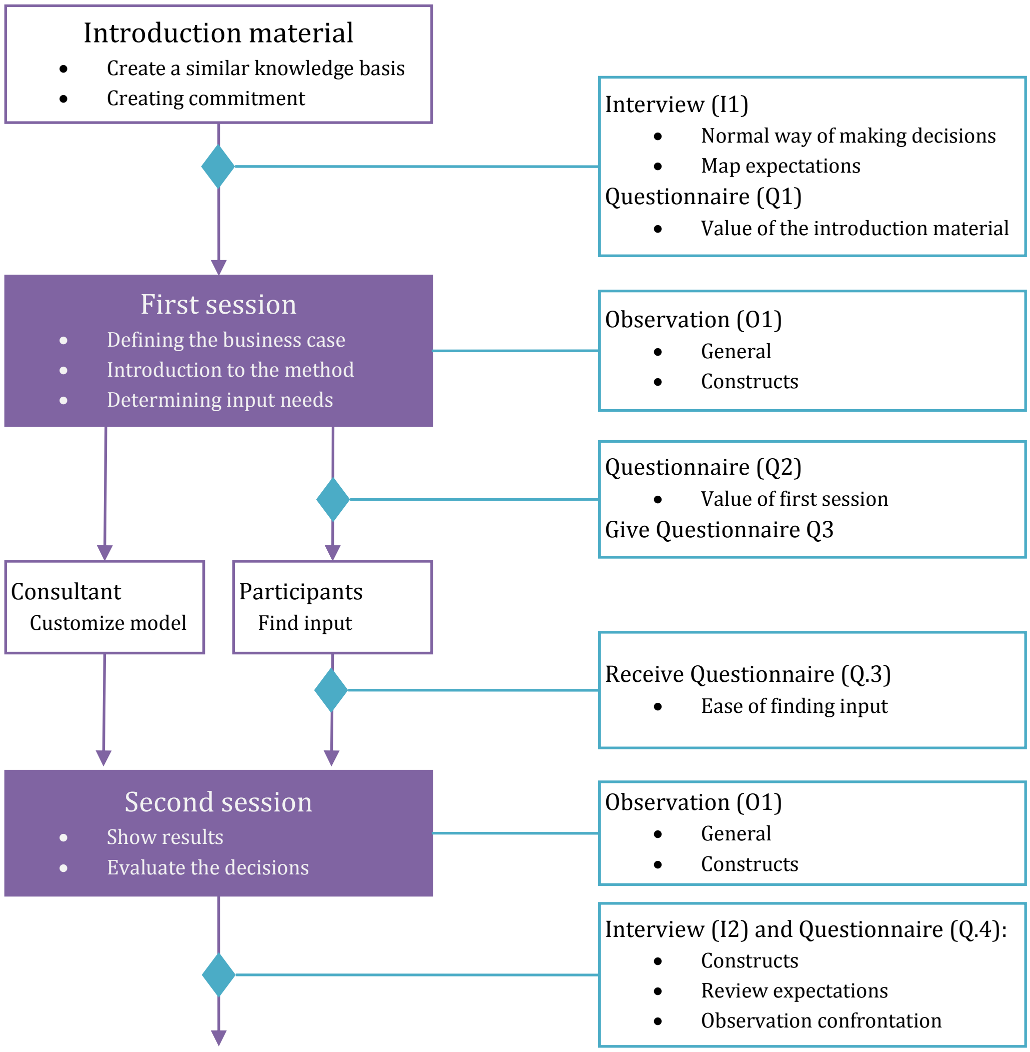
A case study is a useful research strategy when one is interested in obtaining in-depth, quantitative knowledge with a relative small amount of research objects (Verschuren & Doorewaard, 2007, p. 184). This study is interested in results that are complete and real. This means a preference for in-depth results rather that broad scoped results. Since the framework is relatively new and the value in practice is little known, qualitative data is preferred to quantitative. Because of these characteristics, a case study is chosen as research strategy.

The case study will be comparative, i.e. multiple cases will be examined and compared. This helps to come to abstract conclusions. Since little is known about the value of the method in practice, it is hard to predict the issues that will be encountered during the case study. Therefore the method of snowball sampling will be used. This means that cases are examined sequentially and are selected based on results from the previous case. Cases need to meet at least the following criteria:

1. At least two business functions are affected by the architectural choice
2. The architectural problem is not trivial to solve
3. The problem must be relevant to the participants

Research procedure

The figure below depicts the procedure that is used in the case evaluation.



The procedure consists of four stages, indicated in purple. The highlighted boxes are group stages, whilst the others indicate individual stages. Several measuring points are created to gather information. These are depicted on the right. The process itself is discussed in the main document. Therefore, this appendix will only discuss the measuring points indicated on the right.

Interviews are useful to obtain qualitative insight on the value of the framework in a short period of time. Therefore, they will be used as a main way of obtaining information from the participants and are not skipped. The interviews are semi structured and based on a topic list. They will be taped and transcribed.

The intermediate measuring points are relatively short and consist of short questionnaires and observations. They help when groups are rather large and not all participants can be interviewed. Furthermore they can capture information that people notice after the sessions. Keeping the intermediate points short reduces the time burden on the participants. For the same reason the researcher has the freedom to skip or merge several of these intermediate measuring points.

The last questionnaire (Q4) is the main questionnaire. It is based on an operationalization of the constructs, which is depicted in Exhibit 4.

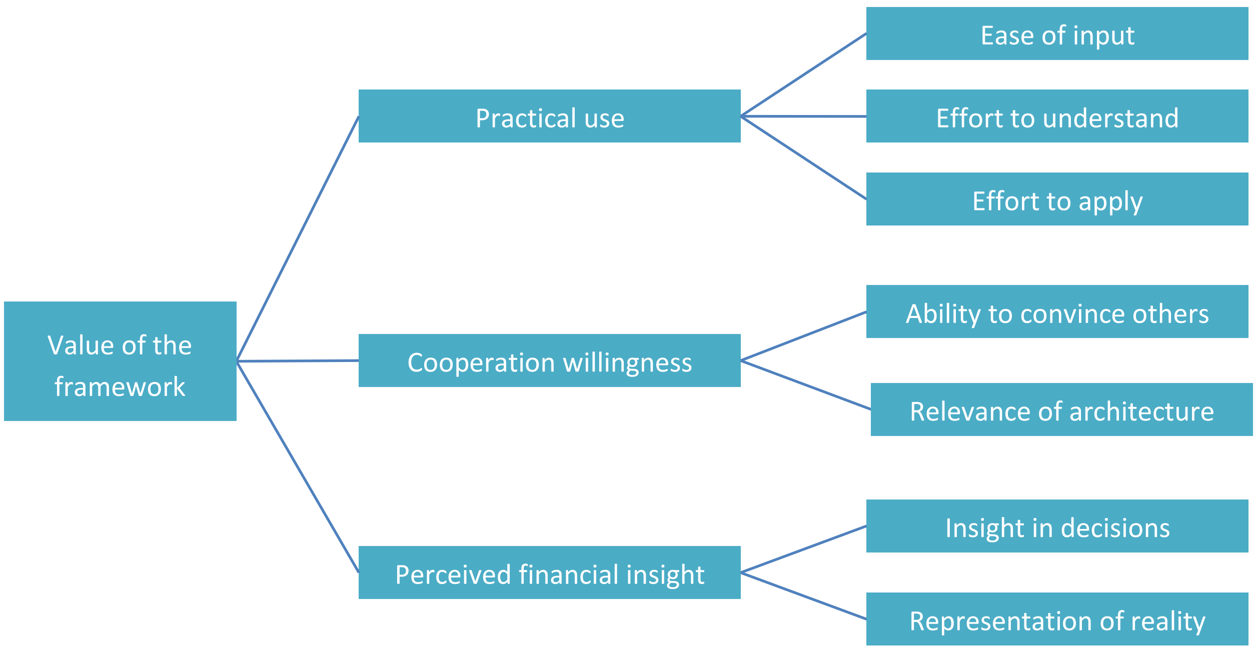


Exhibit 4 - Operationalization of the constructs

All questionnaires and topic lists or the interviews can be found in Appendix D.

Appendix D Questionnaires and interview topic lists

Interview I1 (30 minutes)

When: Before the first session

Who: A small group or individual initiating persons

Put the tape recorder on

Topic list

- Describe if and how you have encountered strategic architectural decisions in your work
- Describe the way you normally make strategic architectural decisions
- The main problems in decision making, e.g. (start over these topics)
    - Figuring out the effects of decisions? Dealing with uncertainty?
    - Cooperation with other departments? Convincing management, others?
    - Practical issues? Time?
- Describe the best possible outcome of this method

Questionnaire Q1 (1-5 minutes): Answer before the first session

Instructions

You are encouraged to discuss issues that pop into your mind with the researcher when filling in the questionnaire or once you finished it. You can also write them down on this sheet. If a question is not applicable to your situation, you can leave it open.

Name

Only for the administration of the researcher. Results are processed anonymously

	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree
I think that the introduction material is useful	x	x	x	x	x	x
Up to now my attitude towards the method is positive	x	x	x	x	x	x

I think you could improve the introduction material in this way (optional):

Other remarks (optional):

Thank you for your time and effort

Questionnaire Q2 (1-5 minutes): Answer directly after the first session

Instructions

You are encouraged to discuss issues that pop into your mind with the researcher when filling in the questionnaire or once you finished it. You can also write them down on this sheet. If a question is not applicable to your situation, you can leave it open.

Name	

Only for the administration of the researcher. Results are processed anonymously

	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree
It is clear to me what to do before the second session starts	x	x	x	x	x	x
I know what kind of input I need to find now	x	x	x	x	x	X
Up to now my attitude towards the method is positive	x	x	x	x	x	x

I think you could improve the first session in this way (optional):

Other remarks (optional):

Thank you for your time and effort

Questionnaire Q3 (1-5 minutes): Take home, hand in before the second session

Instructions

You are encouraged to discuss issues that popped into your mind with the researcher. You can also write them down on this sheet. If a question is not applicable to your situation, you can leave it open.

Please answer these questions not too long before the second session starts

Name

Only for the administration of the researcher. Results are processed anonymously

	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree
It was easy for me to find input data	x	x	x	x	x	x
I thought about the method and the case regularly	x	x	x	x	x	X
Up to now my attitude towards the method is positive	x	x	x	x	x	x

I think you could improve the method in this way (optional):

Other remarks (optional):

Thank you for your time and effort

Interview I2 (ca. 1 hour)

When: Before the first session

Who: A small group or individual initiating persons

Put the tape recorder on!

Topic list

General value

- Do you think the method is valuable? To what extent?
- Does the method improve decision making?

- What do you miss in the method?

- Would you like to use the method in the future? Why?

Constructs

- Is the method easy to apply? Why?

- Do you think that the method gives you get a better insight in the financial effects of decisions? Why?

- Do you think that the method facilitates cooperation between departments in decision making? Why?

Confrontation with the observations

Evaluate expectations from interview I1

Now do questionnaire Q4

Closing statements

- Thank you for your time and effort. Do you have any final suggestions for improvement or remarks?

Questionnaire Q4 (ca. 10-15 minutes): after the second session or during the final interview

Instructions

You are encouraged to discuss issues that pop into your mind with the interviewer when filling in the questionnaire or once you finished it. You can also write down your remarks on the right. If a question is not applicable to your situation, you can leave it open.

Name	

Only for the administration of the researcher. Results are processed anonymously

Perceived value	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
I can use this method to make better decisions	x	x	x	x	x	x	
I want to use **a method** to make strategic architectural decisions in the future	x	x	x	x	x	x	
I want to use **this method** to make architectural decisions in the future	x	x	x	x	x	x	
The results are useful to me	x	x	x	x	x	x	
The method complements existing ways to make strategic architectural decisions	x	x	x	x	x	x	

Ease of input	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
I can gather input data for the method easily	x	x	x	x	x	x	
I depend too much on others to gather the input data	x	x	x	x	x	x	

	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
I prefer to give input in ranges instead of fixed numbers	x	x	x	x	x	x	
The input of the model is intuitive	x	x	x	x	x	x	

Effort to apply	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The method is easy to apply	x	x	x	x	x	x	
How much time did the method take including preparations?							
The method requires too much time	x	x	x	x	x	x	
The method is too much focused on one discipline	x	x	x	x	x	x	
The introduction of the method is too long	x	x	x	x	x	x	

Effort to understand the model	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The method is easy to understand	x	x	x	x	x	x	
It is clear to me what the output of the method represents	x	x	x	x	x	x	
The method is too complex	x	x	x	x	x	x	
It is easy to understand how the method works	x	x	x	x	x	x	
The methods requires little clarification	x	x	x	x	x	x	

Almost done…

Relevance of cooperation in architecture	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The method can improve communication between business functions	x	x	x	x	x	x	
The method can facilitate in making decisions with other business functions	x	x	x	x	x	x	
The method helps to discuss the views of different business functions	x	x	x	x	x	x	
The company would benefit from making strategic architectural decisions together more often	x	x	x	x	x	x	

Ability to convince others	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The method helps to convince management of strategic architectural decisions	x	x	x	x	x	x	
I can use the results to explain architectural decisions to others	x	x	x	x	x	x	
The method helps to make tradeoffs between conflicting interests	x	x	x	x	x	x	

Insight in architectural decisions	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The model provides insight in financial effects of architectural decisions	x	x	x	x	x	x	
The method makes it easy to see consequences of an architectural decision	x	x	x	x	x	x	
The method shows the tradeoffs between different architectural decisions	x	x	x	x	x	x	
The method creates awareness of various strategic decisions	x	x	x	x	x	x	

Representation of reality	strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree	Possible remarks
The decisions in the method apply to my situation	x	x	x	x	x	x	
The model addresses relevant problems	x	x	x	x	x	x	
The model includes all relevant factors	x	x	x	x	x	x	
The model represents reality better than conventional methods because it models uncertainties and choice	x	x	x	x	x	x	

If you have any suggestions for improvement of the method, or any other remarks, please state them below (optional):

Thank you for your time and effort

Testing plan

Questionnaire Q1: after the introduction material

Who: All participants
Give: After the interview I1, before the first session
Receive: Before the first session starts

Questionnaire Q2: directly after the first session

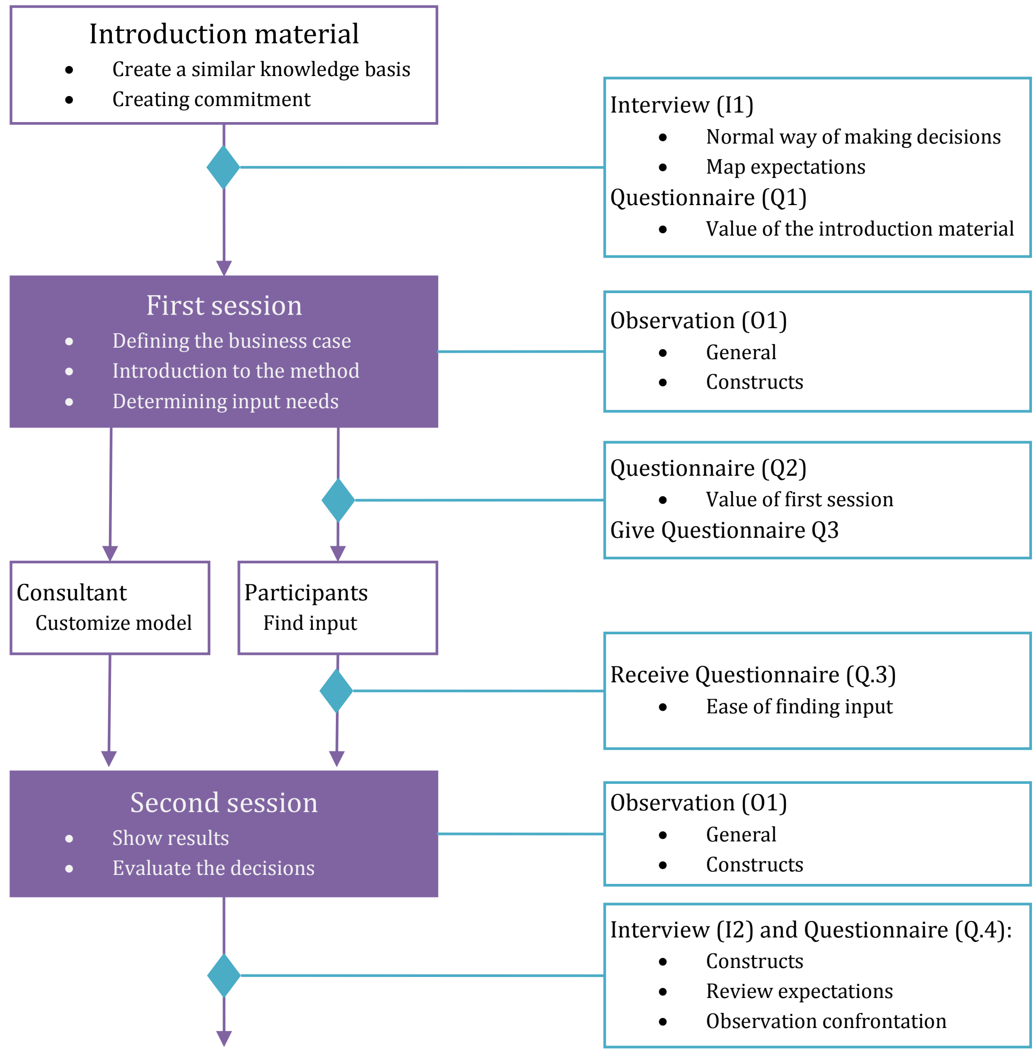
Who: All participants
Give: After the first session
Receive: After the first session, before participants leave

Questionnaire Q3: before the second session

Who: All participants
Give: After the first session, to take home
Receive: Before the second session

Questionnaire Q4: after the second session or during interview I2

Who: All participants
Give: After the first session, to take home
Receive: Before the second session



Appendix E Introduction Material

Abstract

When you design a product, you can make many strategic decisions that have a big impact on the company. Usually the decision that generates the most money is made, i.e. the one that has the highest Net Present Value.

However, it is often hard to make the best decision. After all, there is usually a lot uncertainty about the future and you can adopt your strategy in the future as well. This method tries to help in making the best strategic decision, by determining the financial consequences of each of these decisions.

Architectural decisions can have a big impact on the company

When a new product is designed, you want it to last for several years. Therefore you have to consider to include developments in the market and technology into your product architecture. These strategic decisions need to be made in an early phase. Typical questions that one may face are:

- What to do with a future market trend? (e.g. preparing it for foreign export)
- Should the product be prepared for extra product variants? (e.g. extra features)
- Should we incorporate a promising new technology? (e.g. a wifi chip)

Obviously, these decisions are not only relevant for R&D, since they can have a significant impact on other business functions like production, logistics, marketing and sales. They can really lead to extra sales or induce more costs. Therefore neglecting these decisions early in the product development phase may have profound implications on the business. The final section of this document provides an example that illustrates this effect on the business.

Four decisions can be made

In many cases, there are four decisions that can be made to deal with these strategic questions. These are depicted below. Each of these decisions will now be discussed briefly.

The situation

For instance, take the example of including a wifi chip into the product. There is a possibility that some people might require this functionality in the future and are willing to pay extra for it. Even worse, if you cannot offer this functionality, a number of customers will be lost to competitors. However, there is also a possibility that no customers will require the wifi functionality at all. What to do?

Decision 1: Include in all

An option would be to include the wifi chip standard in all products with a disabled functionality. Once the market requires the functionality, you can launch it very fast and gain a good market share. Furthermore, there are little changes in the supply chain. The trade off however is that it costs money to include the chip, which is lost if nobody requires the functionality. If the chip is not very expensive this might be a good option.

Decision 2: Prepare for the future

The second decision could be to build a preparation into the product. For instance, an interface for the wifi chip could be made. If the market requires it, there will be already some preparations in the product and the time to market would be relatively fast as well (although probably not as great as when the chip was included). However, there will also be some redesign costs to implement the chip. This means that managers will only decide to launch the chip in the future, if it outweighs these implementation costs. Therefore, there is a possibility that the feature will not be launched at all. Then the costs of the interface should be seen as a loss.

Decision 3: Discard the option

In some situations excluding functionality deliberately can lead to cost savings. However, the consequences are so drastically that it is virtually impossible to redesign the product and include the functionality in the future. For instance, discarding the wifi functionality could require a cheaper computer system, but this is so integrated into the rest of the product that an entire new product has to be designed if the functionality is needed. It therefore in effect rules out any revenues of the new functionality.

Decision 4: Do nothing

The final decision could be to not prepare for the future, but not excluding the possibilities for redesign as well. Of course this does not cost any money now. However, there are some tradeoffs. When the market requires the feature the time to market is slow because the product needs to be redesigned. Furthermore, redesigning usually comes at a relatively high cost.

It is hard to make the best decision

It is usually very hard to determine the best decision. After all the best decision is very case specific and it is not easy to calculate which decision generates most money for the company, mainly because:

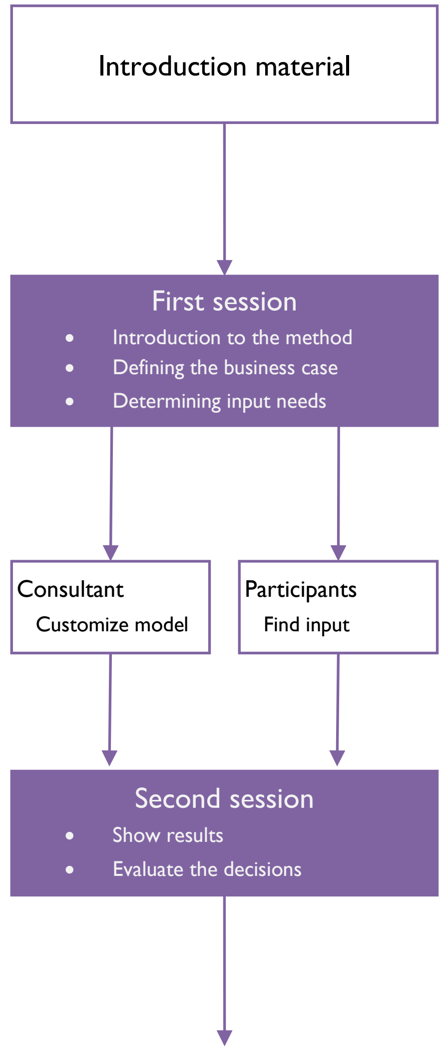
- There is high uncertainty about the future market demand
- If you make a decision now, you can still react in multiple ways in the future by deciding to launch the functionality or not

Although there is uncertainty about the future, the reality is tough. After all, it demands you to make a decision now. Most of the times, the decisions are not taken deliberately, but by default. In that case it is likely to be decision 4: do nothing. After all, this choice offers the least resistance since it requires no money initially and does not exclude anything.

> If no attention is paid to product architecture, decision four is the default choice

The goal of this method

This method tries to help in making the best strategic decision, by determining the financial consequences of each of these decisions. It does so by explicitly including uncertainty and choice into the decisions, a concept adopted from option theory on the financial market. The method thus tries to capture what decision is best, but cannot quantify decision down to the single euro. It deals with decision making under uncertainty, but the uncertainty remains.



Practical issues: the first session

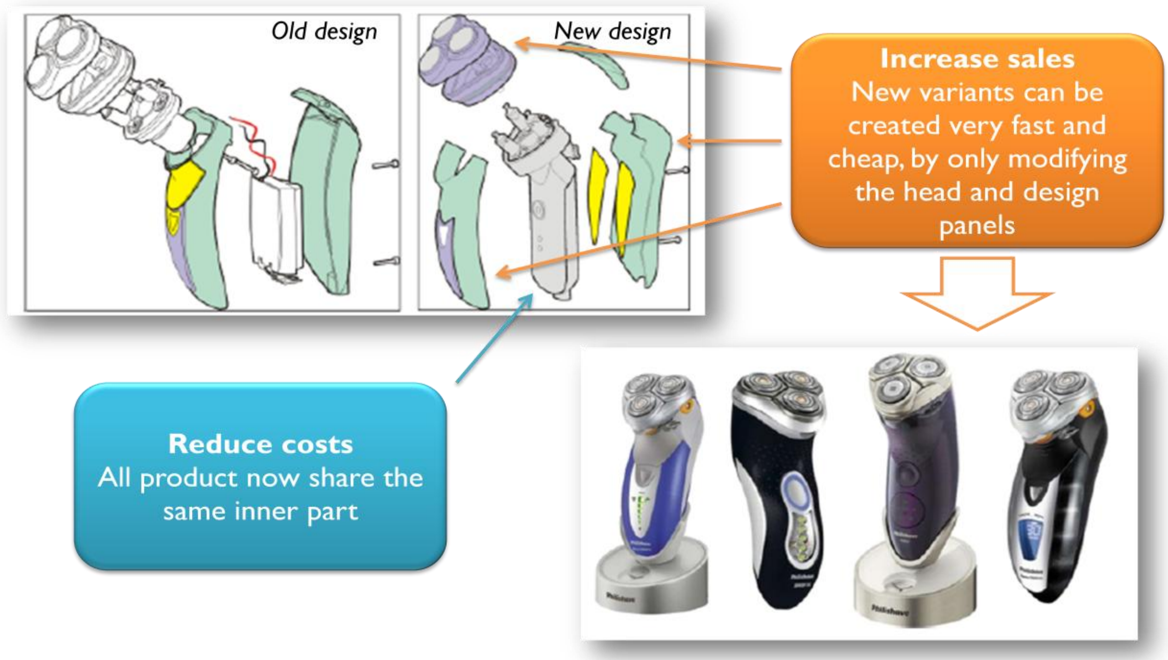
The method is split into two sessions. The first session is used to discuss the method and the business case. After all, precious time will be lost if the method does not represent reality. Therefore, it is essential to develop a similar view of the problem at hand and to reduce it to the essence. Finally the input needs are determined.

After the first session, the consultant tailor-makes the method to fit the specific situation at hand. The participants try to find the essential input data that are unknown. During the process contact between both is likely to occur frequently.

The second session is meant to discuss and evaluate the results of the method.

Illustration[3]: An example of a strategic product architecture

The figure below illustrates a well anticipated strategic product architecture created by Philips.



In the old design every new Philipshave designed to its own specifications. However, people realized that in fact the market really only needed changes in shaving head, interface and design panels. The other specifications remained roughly the same. Therefore a new product architecture was created in which all inner parts (like gears, battery pack and DC motor) were integrated into a single part. The rest of the interfaces was made for flexibility. This had two major effects. First, cost reductions were achieved since the number of parts was reduced dramatically. Second, sales increased since new products could be created very fast and cheap by only modifying the shaving head and design panels. The quality of the shavers was increased as well, since the robust inner part was included in every shaver.

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[3] This part is only meant to illustrate the impact of a strategic product architecture on the company. You may skip it with no loss of content

Appendix F Transcriptions of the cases

Omitted due to confidentiality. Please contact Philips for copies

Appendix G Functions of the Monte Carlo input distributions

Omitted due to confidentiality. Please contact Philips for copies

Appendix H Mathematics of the model

Omitted due to confidentiality. Please contact Philips for copies

Appendix I Visual Basic Code for user interface

Omitted due to confidentiality. Please contact Philips for copies

Appendix J Visual Basic Code for the Monte Carlo simulation

Omitted due to confidentiality. Please contact Philips for copies

Appendix K Visual Basic code for general program functions

Omitted due to confidentiality. Please contact Philips for copies

Appendix L Result sheet of the Icarus case

Results of the Icarus case. Assumptions of the second participant

This scenario assumes that the market will demand the Icarus feature in 2010. If the company can offer an Icarus at that time, a percentage of the current customers will pay extra for this feature. However, if the feature cannot be offered, a percentage of the customers will flee to competitors.

Assumptions and results are now displayed.

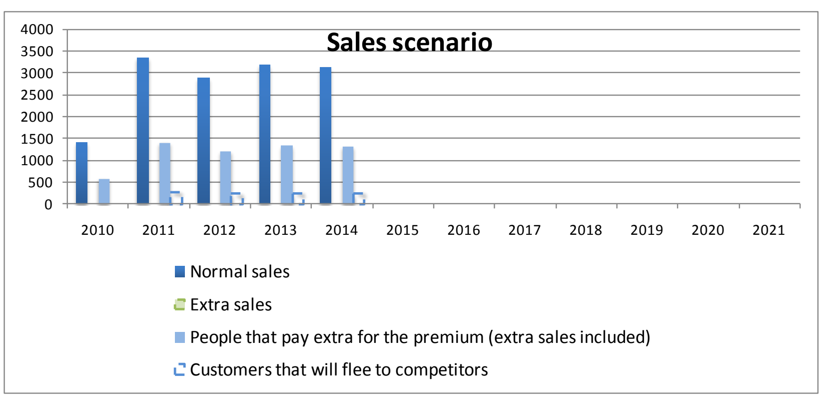
Market assumptions

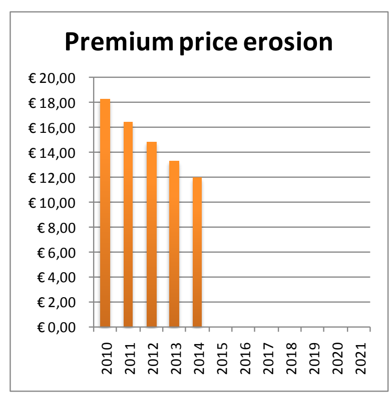
Base case		
Total products sold	2010	1000 - 2000 products per year. The most likely value is 1999
	2011-2014	2500 - 3500 products per year. The most likely value is 3000
Profit per item	2010	30 k€ - 55 k€ per product. The most likely value is 40 k€
	2011-2014	Between 95% and 98% of the previous year
WACC		12%

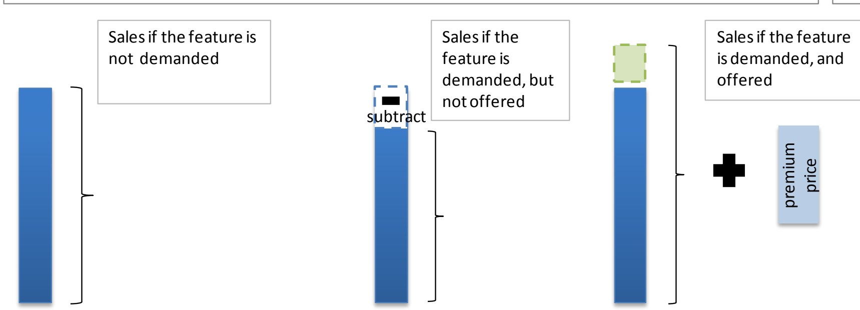
In case that the market requires the Icarus	
Extra systems sold	0%
Percentage of all customers that pay for the Icarus	30% - 70%
Extra profit made per Icarus in the first year	10k€ - 25k€. The most likely value is 17k€
Price erosion per year	10% loss in profit per year
If the market requires the Icarus feature but it cannot be offered, this percentage of customers flees to competitors	0% - 10%
Time before customers start fleeing to competitors after the first offer	1 year

Visualisation of the market

This one possible scenario of the assumptions above



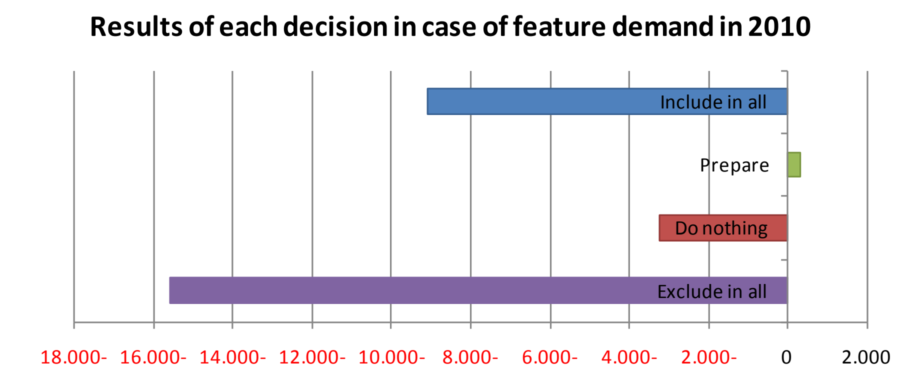




Assumptions of the decisions

Include in all	
Initial development cost	5000-6000 k€
Cost per product sold due to the inclusion of the Icarus	5-10 k€
Prepare	
Initial preparation cost	2000 k€
Preparation cost per product	0,5-1,5k€
Implementation cost	4000-7000 k€
Cost per product with the Icarus	5 – 15 k€
Time to implement once it is decided to offer the Icarus	9 months
Do nothing	
Initial development cost to redesign the product	6000-9000 k€
Time needed to redesign the product	18 months
Cost per product with the Icarus	9 – 15k€
Exclude in all	
Cost savings per normal product sold	None

Results per decision at market demand in 2010



	Exclude in all	Do nothing	Prepare	Include in all
Result	15.548-	3.246-	295	9.088-