Framework for Enterprise Uncertainty-Driven Decision-Making

Aias Martakis

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Framework for Enterprise Uncertainty-Driven Decision-Making

by Aias Martakis

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Dr. Maya Daneva
Electrical Engineering, Mathematics and Computer Science
Services, Cybersecurity and Safety
University of Twente, the Netherlands

Dr. Maria Eugenia Iacob
Behavioural, Management and Social sciences
Industrial Engineering and Business Information Systems
University of Twente, the Netherlands

Dr. Dick Quartel
Research and Development
BiZZdesign, the Netherlands

"Ό,τι δεν λύεται κόπτεται"

Μέγας Αλέξανδρος (356-323 π.Χ.)

feud

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Abstract

Decisions in an enterprise are often complex and deal with many uncertainties. Uncertainties, if left unmanaged, can hamper value creation, lead to loss of value or even result in catastrophic failure. This research proposes a framework for decision-making that explicitly incorporates uncertainty and attempts to manage it by distilling risks for mitigation. One mitigation strategy is to invest and incorporate flexibility by leveraging Real Option Analysis (ROA). ROA provides a theoretical foundation that quantifies the value of flexibility. The Enterprise Architecture (EA) of an organization is the enterprise wide model that aims to describe and align business and IT architectures with a goal of optimizing the creation of value. EA however deals with many uncertainties because of the highly dynamic and complex environment typical in modern business and its IT environments. Viewing EA as a series of decisions makes the introduction of a decision-making framework possible and able to support optimization of value creation throughout the enterprise.

The framework introduced in this thesis aims to provide the structure for this holistic decision-making in an EA context by directly dealing with uncertainty. Its contribution consists of a process-model, a decision-making cycle, designed to be used on top of regular EAFs to support complex decision-making in an EA. The process identifies uncertainty by characterizing uncertainty as endogenous, expecting uncertainty to originate from capabilities inside the enterprise and therefore aligns itself with existing capability maturity models, or as exogenous where uncertainty originates from a corporation's context. This characterization allows for an integration with the ISO 31000:2009 risk assessment process by distilling risks (risk identification) from aforementioned uncertainties. Identified risks can broadly be treated through avoidance, reduction, sharing or retention. One of the ways risks can be reduced effectively is by hedging the risks and reduce vulnerability to its effects and therefore their potential to create loss of value or a catastrophe in an enterprise. The framework integrates the use of Real Option Valuation to valuate potential flexibilities that are expected to hedge such risks and aims to create a context for the use of Real Options in line with existing EA literature.

The research further contributes a visual meta-model that supports communication of the concepts required for decision-making under uncertainty. It leverages the Archimate EA modeling language by extending its elements to support the documentation and modeling of decisions, uncertainties and options and uses existing concepts to model and integrate risks and capabilities.

These contributions are demonstrated in a case study of an insurance company that includes examples of supportive tools that implement the concepts. The insurance company uses a TOGAF EAF with Archimate modeling and it therefore further demonstrates the integration with these industry leading standards. The used tools include various spreadsheets and code for option valuation and Archimate models for visualization. The financial calculations have been evaluated by a financial specialist and the overall concepts were evaluated in a focus group and questionnaire involving various industry and academic experts.

Acknowledgments

This thesis completes my research project principal to obtain a master of science degree at the University of Twente. Returning back to the university after having worked for a significant number of years in the industry brought both its challenges but also a renewed focus. This thesis is the result of many months of academic dedication and I believe it strengthens and embodies my professional skill and prepares me for next steps in my career.

The research was made possible by many people, whom without their support it would have been much more difficult.

I'd like to express my gratitude and thank Dr. Maya Daneva for her continued guidance and insights that made this journey possible. Her enthusiasm, supervision and extensive academic knowledge have been inspirational throughout my research. Our discussions always gave me much acumen to digest and helped me explore many new academic areas. She helped me set up this research, gave me much freedom to explore interests, as well as continuously supported me personally for which I'm very grateful.

Dr. Maria-Eugenia Iacob provided me with her unique insights in enterprise architecture and her practical guidance that helped shape this research to completion. Her critical questions and feedback kept me on my toes and always were a source of reflection. I in particular like to thank her for agreeing to supervise my research as with my background in computer science she provided a needed business management perspective and its theoretical rigor.

I would like to thank Dr. Dick Quartel for providing me with this research opportunity and providing me with crucial industry insight as well as academic guidance within BiZZdesign. He also supported me through some difficult challenges in my personal life for which I'm very thankful.

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These last years have been a journey where I've had the pleasure of experimenting with new ways of thinking, get more insight into- and contribute to the world of academics. Above all I learned much about my own strengths and weaknesses which I believe will help me find my place in life and happiness. I want to thank my friends and family for standing by me through this endeavor and by believing in my abilities even when my own sometimes became tempered. Elizabeth, thank you for your love and your patience, without it I would be nothing. I believe these years were an investment that are the beginning of something great.

Aias Martakis

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Chapter 1

Introduction

1.1 Background

Enterprise Architecture (EA) continues to receive interest of both practitioners and academics as can be seen by the proliferation of many frameworks such as TOGAF, the Zachman Framework and Gartner Methodology as well as numerous publications in journals (Rouhani, Mahrin, Nikpay, Ahmad, & Nikfard, 2015). EA methods have seen a shift from their origins in IT towards a more holistic perspective of an enterprise that puts emphasis on non-technical aspects. The creation and (sustainable) maximization of business value is of key importance to the modern enterprise. The alignment, fundamental in EA, of business and Information Technology (IT), termed strategic alignment (Henderson & Venkatraman, 1993), aims to orchestrate activities and assets and maximizes value.

Success of a corporation is related directly to decisions made on its EA as IT now more than ever is a direct driver for economic performance in an enterprise. EA decisions, not only due to the fast pace of advancements in IT itself, are subject to increasing uncertainty due to the complex and fast changing business environment IT supports and now more and more creates. Most decisions on investments, i.e. the allocation of capital, originates at executive levels of an enterprise. Correlating decisions however are required on many different investments across an organization and may involve many decision-makers. This complex network of capital allocation is often organized in portfolios to make them more manageable. A good portfolio balances the investments through diversification across numerous characteristics such as risk level, expected gain, the term of the investment and are found throughout an EA on both activities (in changes from a base to target architecture) and architectural assets (IT systems, processes, etc.).

Considering all the activity on the subject of EA surprisingly many Enterprise Architecture Frameworks (EAFs) are characterized by a lack of theoretical or conceptual academic foundation and on a whole are still largely driven by industry expert knowledge (Saha, 2006). Little has been done to quantify, in financial terms, the value of EA and therefore the impact EA investments have on economic performance. Viewing EA as a decision making process allows for value optimization through the selection of alternatives that are forecasted for maximum value. Research (Alkaraan & Northcott, 2006) shows quantified forecasting in the industry predominantly takes place through traditional capital budgeting methods such as Net Present Value (NPV), Internal Rate of Return (IRR) and simple payback period calculations. It is expected that dealing with uncertainties systematically can expose the risks to the economic performance of an investment early in the decision process. Traditional forecasting methods however do not value the decisions maker's ability to change their course, and therefore do not value any flexibility that responds to risks that occur, throughout a forecasted period. Real Options (ROs) can be designed such that they mitigate risks by providing this desired flexibility. Analogue to financial options, ROs provide a decision maker the right but not the obligation to exercise actions at a later time (Myers, 1977). Therefore, investing in a Real Option (RO) can give an enterprise the flexibility to respond to changing conditions during the exercise time of this option by exercising the option if/when this makes financial sense i.e. when the value of exercising the option exceeds continuation without it. Discovering uncertainty and designing for flexibility impacts the architectural designs across an EA. A fundamental problem with EA is that important decisions typically are made, when knowledge is the lowest, at the start of architecture transitions. It is argued that having a choice is often more important than the choice itself (Monson-Haefel, 2009) and that the design of architecture should therefore be made such that changing it becomes less significant (Booch, 2009). By identifying a lack of knowledge (i.e. an uncertainty) early and designing EA for flexibility, through the investment in- and design of- ROs, decision making can be deferred until (more) knowledge becomes available.

While most Enterprise Architecture Frameworks (EAFs) have focused on lowering cost through structure and technical efficiency, rather than explicitly modeling business value (Saha, 2006), this thesis aims to propose an integrated value driven approach to EA decision making that directly links EA investments decisions to potential value and flexibility. The Framework for Enterprise Uncertainty-Driven Decision-Making (FEUD) argues for a systematic and integrated use of option thinking through Real Option Valuation (ROV) theory on investment decisions and early discovery of risk through uncertainties. This systematic decision-making is expected to extend any existing EAF practices in a corporation and improve communications between decision-makers (typically executives) and enterprise architects. By designing EA to incorporate flexibility, such that changes due to manifesting risks can be mitigated, the enterprise's ability to adapt to changing circumstances is increased and therefore Enterprise Agility promoted.

1.2 Motivation

The author's initial motivation for this research is founded in personal experiences as a practitioner in various functions described by EA, ranging from network administration to software development, business process engineering and work in a strategic capacity. These all dealt with making decisions or responding to decisions made by others with high levels of uncertainty, as can be seen as typical in companies that operate in a fast growing and still maturing industry. These experiences supported findings in literature that much decision-making still not only happens unstructured, but often under high-pressure, without much grasp on the uncertainties and therefore creates a great deal of risks. After being introduced to Real Option theory, in the context of valuation of security investments in particular for Oil and Gas companies (Franqueira, Houmb, & Daneva, 2010; Emerick et al., 2009), curiosity arose to see how and if ROs could be of value in an EA context. Most RO literature describes the valuation of a single investment decision and most of the times this was limited to strategic decisions. Recent years have however seen literature that explored other types of investment decisions and valuations (Zeng, 2011; Aarle, 2013), and also various research on different valuation techniques, in particular volatility estimations (Godinho, 2006; Luiz E. Brandão, Dyer, & Hahn, 2012; Haahtela, 2011; Mun, 2002). To date only limited literature exists that explores ROV in the context of EA decision-making, with the most notable work in this area from Mikaelian (2009), Olagbemiro (2008), Saha (2006). This thesis builds upon this work by combining and extending theories and by putting EA decision making and ROV in context. It therefore also extends the enterprise architecture body of knowledge by suggesting new modeling-elements and putting emphasis on the modeling of decisions and options. The FEUD framework integrates ROV with uncertainty, capabilities, environmental analysis, risks and opportunities in EA decision making.

Chapter 2

Research

2.1 Research problem

Little theoretical frameworks exist, either in academics or developed by practitioners, that support integrated decision-making throughout an Enterprise Architecture (EA). Consequently, not enough is known on how to measure the business value EA investment decisions promises to deliver. Practitioners are often left to make architectural decisions based on intuition or expert advice without fully understanding their impact on the bottom line. A rising complexity in EA, due to a dynamic business environment and a rapidly changing IT landscape, causes EA decision-makers to deal with increasing uncertainty. Uncertainty if treated early can create both opportunities and mitigate further risks and provides an opportunity to increase an investments value and competitive advantage. Traditional investment valuation methods however provide decision makers with inaccurate value estimations as they do not account for their ability to respond to the uncertainty of future events (i.e. such opportunities or risks). Flexibility can be very valuable for in particular high risk investments, that often also have the higher potential for profit. These high-risk investments therefore are undervalued in traditional methods. Research & Development (R&D) projects and most EA transitions are investment examples that typically involve high risks, require steep initial investments and offer little short-term returns. To no surprise EA practitioners have often struggled with negative perceptions on the business value EA creates.

EA attempts to create a holistic view on an enterprise and its IT with the aim to align these with its business. Decisions in one aspect or dimension of EA therefore affect and interrelate with other decisions. Flexibility identified and desired on those decisions consequently can also affect other decisions. For example, the flexibilities on a strategic level can introduce constraints or can require flexibility on projects that implement this strategy. Decision making in EA therefore requires the same holistic perspective to be effective. This holistic perspective should be supported by EA models that integrate the assets in the different EA dimensions involved in the decision. To date no decision-making elements formally exist in EA models and no decision-making process supports making decisions holistically in an EA. While Real Options (ROs) have been introduced in various different domains that are relevant to EA, limited research explores their use throughout an EA and no framework exists that structures decision-making under uncertainty in existing Enterprise Architecture Frameworks (EAFs).

2.2 Research context

This research was performed in- and made possible with- the participation of BiZZdesign. BiZZdesign was founded as a spin-off company in 2001 of the Testbed project, a large international research that involved the University of Twente, several other universities and various multinational companies such as IBM, Phillips, KPN and ING. BiZZdesign has since become a leading EA and business process modeling software and service supplier and is known in the industry for its co-development of the Archimate modeling language, now an open technical standard from The Open Group that describes EA. BiZZdesign has an international clientele spanning much of the globe and offers various services, (software) tools and training related to EA such as lean management and governance, and risk and compliance. BiZZdesign has often featured in Gartner's Magic Quadrant and were positioned as leaders for EA tools in 2014. The research anticipated interdisciplinary academics that included schools of thought in economics, business and engineering. It therefore was constructed and performed with the academic supervision that includes expertise from both the University of Twente faculties of Electrical Engineering, Mathematics and Computer Science (EEMCS), provided by Dr. Maya Daneva, and Behavioral, Management and Social sciences (BMS), provided by Dr. Maria Iacob. Added supervision from Dr. Dick Quartel of the Research and Development (R&D) department of aforementioned BiZZdesign further bridged academic fields and included industry feedback and insight. This research received additional support from Dr. Henk Kroon from the Computational Finance and Risk Management department (CFRM) in the BMS faculty on financial aspects, in particular on the Real Option Valuation (ROV) and Discounted Cash Flow (DCF) calculations.

2.3 Research goal and objectives

The research problems described in section 2.1 provide an opportunity to set research goals. At the highest level the goal was to **structurally improve EA investment decisions**. In achieving this goal a general objective was set to **create an investment decision-making framework that can be used in an EAF** and formulated the following specific objectives:

1. Identify how and when decisions on investment options are made in an EA.
2. Research uncertainty and its origins and effects on EA decisions.
3. Determine investment valuation methods for EA decisions.
4. Develop a decision-making process that supports EAFs such as TOGAF.
5. Design Archimate elements for EA decision modeling.
6. Research ROV methods and determine their use in EA decision valuation.
7. Develop easy tools that conceptually support the decision making process.
8. Demonstrate and evaluate the designed framework in a case using Archimate notation.

The research initially focused on exploring how the ROV methods could be used to improve EA modeling. This more narrow research view was ultimately widened, in agreement with supervisors, by including objectives for EA decision-making. When no decision-making frameworks for EA were found in literature it was decided to explore and develop a state-of-the-art decision-making framework for EA that could provide a necessary context for the use of ROV in EA.

2.4 Research questions

Research questions are identified and formulated to accomplish the goals set out in the previous section. The main research question that forms the center of this research is formulated as follows:
How can EA investment decisions structurally be made more effective and account

for uncertainty throughout an enterprise?
This main research question can be further divided in the following more specific research questions:
First the research focuses on the definitions and concepts required to construct the framework. These are answered by performing a review of academic literature as detailed in chapter 3:
RQ1: How can complex EA investment decisions be modeled in an enterprise?

- How are EA decisions made holistically throughout an enterprise?
- What (types of) problems do decision-makers encounter when making architectural decisions?
- How are EA decisions related to investment options and alternatives?
- How can decisions, options and alternatives be modeled?
- What creates uncertainty in an EA?
- How does uncertainty affect EA decisions?
- What value quantification methods exist for EA?
- What are current problems with value quantification in EA?
- What decision-making strategies exist?

Next the research concentrates on ROV methods and how they relate to EA. The theory, sourced in literature, was applied by creating ROV artifacts, such as calculations, for use in EA decision making. These are further demonstrated in the case study.
RQ2: What is an architecture based ROV method?

- How does ROV value EA investments?
- How can ROV account for uncertainty in EA?
- What ROV calculation methods exist?
- How can ROV support integrated EA decisions?

Last the previously explored methods and concepts are integrated in a single process and framework.
RQ3: How can the EA decision-making process be structured?

- What are the phases of decision-making?
- How can decision-making deal with uncertainty?
- How can available ROs be discovered?
- When and how can ROV methods be integrated in a decision-making process?
- How can the (real) options be included in EA decision-making strategies?

2.5 Limitations and scope

The decision-making cycle and the supportive tools are aimed at decision-making in an EA context. Many EA decisions typically are of a scale, based on the size of the investment(s), number of involved (EA) assets, and/or the forecasted (implementation/write-off) period that can warrant investment in a more formal and structured decision making framework. This research was performed in the context of BiZZdesign and the framework's design and development are geared towards the methods used in the organization. Although it is by design generic, its use is demonstrated in an Archimate oriented environment. Full implementations that evaluate the artifact in the industry are beyond the scope of this thesis, as per the design cycle, instead a prototype is demonstrated in a realistic case study evaluated by experts both directly and through a survey.

2.6 Research purpose

The overall purpose of the research is of exploratory nature and its main objective is to identify and explore the key issues and variables that relate to making effective decisions on investments that face uncertainty in an EA, as stated earlier, and propose an artifact that deals and improves these. A focus is set on the relationships of these variables in order to provide a base to develop specific hypothesis on in future research. To connect ideas and to understand cause and effect a thorough literature review is performed first. This, the input from experts and personal experiences form the base of the proposed framework that is subsequently demonstrated. A qualitative approach to evaluation is warranted and performed in the form of a focus group, through meetings with experts and by using a questionnaire. The following section gives further insight in how the research is structured and defined as a design science research.

2.7 Research design and methods

2.7.1 Study design and evaluation

Design science seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts (Hevner, March, Park, & Ram, 2004). Peffers, Tuunanen, Rothenberger, and Chatterjee, broaden the definition for these artifacts to include constructs, models, methods and instantiation but also social innovations, new properties of technical, social or information resources (Peffers et al., 2007). This research proposes such new artifacts and therefore can leverage the Design Science Research Methodology (DSRM) as stated in Peffers et al. (2007), R. J. Wieringa and Morali (2012). The DSRM exists of several steps as seen in figure 2.1.

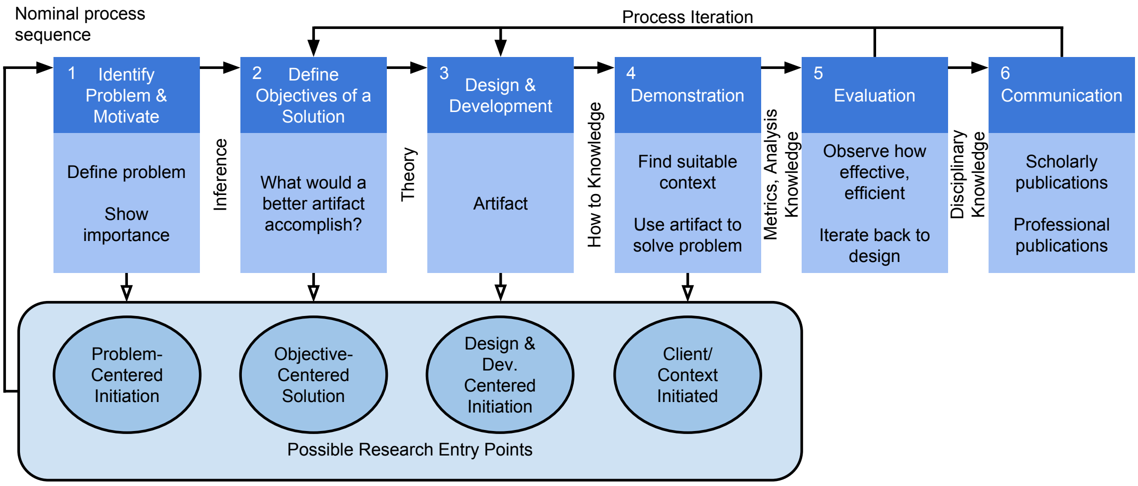


Figure 2.1: Peffer DSRM Process Model

Details are supplied about each activity of the DSRM in figure 2.1:

1. Identify Problem and Motivate. The specific research problem needs to be defined and a justification of the value of a solution should be given. The main objective is "to describe the problem, to explain it, and possibly to predict what would happen if nothing is done about it" (R. J. Wieringa, 2009). R. J. Wieringa and Morali identify the following applicable actions (R. J. Wieringa & Morali, 2012):

   (a) Identification of stakeholders and their goals, which are then operationalized into criteria

   (b) Investigation of relevant phenomena for the problem at stake

   (c) Assessment of how well these phenomena agree with the goals of the stakeholders

2. Define Objectives of a Solution. Infer objectives rationally from the problem specification. This should explain in what way the newer solution will be better than current ones.

3. Design and Development. Design and develop treatments, the interaction of artifacts in the problem context.

4. Demonstration. Demonstrate, in for example simulations, a case study or proof, the use of the artifact to solve one or more instances of the problem.

5. Evaluation. Compare the objectives stated earlier with the actual results observed from the use of the artifact in the demonstration and predict how the artifact will perform in practice. R. J. Wieringa and Morali distinguishes the following validation question categories (R. J. Wieringa & Morali, 2012):

   (a) Effect questions. What will the effects of the artifact be in a problem context?

   (b) Trade-off questions. How does the treatment compare with other treatments?

   (c) Sensitivity questions. If the problem context changes will the treatment still be effective?

6. Communication. Peffers et al. state the importance of communicating the work done back to the scientific and practitioner community (Peffers et al., 2007). Media for communication includes scholarly articles such as this thesis or professional publications.

Peffers et al., as seen in figure 2.1, indicate that although there is a nominal sequential order, which starts with activity one and ends in six, there is no expectation that researchers actually always proceed in order. The possible research entry points indicate for each activity the triggers for each research starting in the associated activity. The evaluation and communication activities can iterate back to an earlier activity for example when a researcher after evaluation wants to improve the effectiveness of an artifact or after communication with other researchers decides to redefine the solution objectives. R. J. Wieringa captures the same process in a design cycle, see figure 2.2 (R. J. Wieringa, 2014). Note that the design cycle is represented as a sub-cycle of an engineering cycle. In the engineering cycle the designed artifact evolves to a real-world implementation (shown in the treatment implementation phase), which in turn can initiate a new engineering cycle and thus a design cycle.

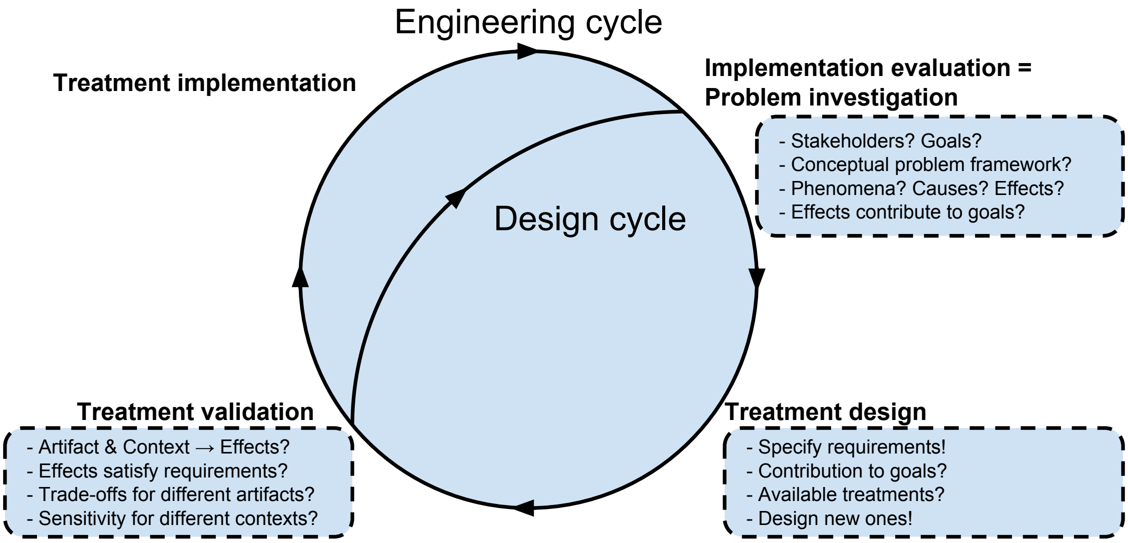


Figure 2.2: Wieringa Engineering cycle

2.8 Performing the Design Cycle

As stated in section 2.1 this research aims to develop a framework, an artifact, to support decision making in an EA through quantification of value that can use real option valuation. Based on Hevner et al.; Peffers et al.; R. J. Wieringa and Morali's definition this can be supported by the described DSRM for a technical action research. Figure 2.3 shows the DSRM process for this research. The following sections will discuss each activity in detail.

2.8.1 Initiation

This research initiated, as explained in section 1.2, out of experiences in EA that dealt with decision-making. It was seen that most EA decisions were made unstructured and without good grasp of the uncertainties involved and therefore heavily relied on the experience of experts. Investments in EA often bear great uncertainty and research shows the majority of EA projects do not yield the expected results (Roeleven, 2010) and suffer from poor forecasting (Cleden, 2009). As complexity continues to increase so does uncertainty and while uncertainty cannot be eliminated it needs to be contained. This research sets out to find a structured way of EA decision-making that copes with uncertainty by exploring real options theory.

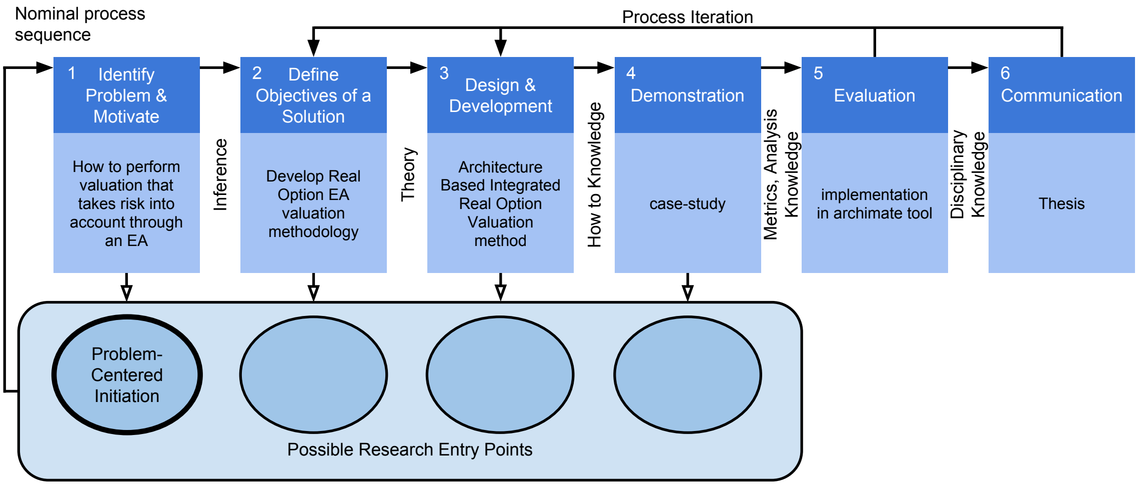


Figure 2.3: Thesis DSRM Process Model

2.8.2 Problem Identification and Motivation

Making decisions that require predictions on the future deals with uncertainty. High levels of uncertainty can slow down or even break down a decision-making process. Decisions on enterprise architecture often decides on or influences future events and therefore intrinsically deals with uncertainty. Most of this decision-making however happens without a systematic process that deals with this uncertainty. A substantiated decision requires knowledge on the involved risks. By systematically distilling risks from uncertainty mitigation strategies can be incorporated in the decision-making process and complex decisions that previously faced uncertainty can then be substantiated. Currently no EA frameworks include such structured decision making under uncertainty and EA practitioners are left to make these decisions based on insight, which could explain the disappointing results of EA projects in the industry (Fichman, Keil, & Tiwana, 2005; Roeleven, 2010).

2.8.3 Objective of the Solution

Real Option theory provides means to mitigate risks on investment decisions by valuating and investing in flexibility. Currently only limited research exist that includes a decision-making framework that supports flexibility valuation through real options in the context of EA. This lack of flexibility valuation methods leads to low appreciation of, in particular, investments in riskier ventures. By incorporating real options to valuate flexibility to mitigate risks it is hoped that investments can be more accurately valued leading to better investment. The identification and design of flexibility is intrinsically included in EA projects which is expected to lead to better containment of uncertainty and a subsequent lower vulnerability to associated risks resulting in these riskier projects to increase in perceived value.

2.8.4 Design and Development

This research produces an framework artifact, detailed in chapter 4 that supports decision-making under uncertainty in an EA. First an extensive literature study on the topics of EA, investment valuation methods, decision-making, real options, risk management, (IT) governance will provide the needed foundation on concepts and theories. This theoretical framework will form the artifacts foundation. Leveraging theory the artifact is build using case examples that are refined iteratively by reviewing academic decisions made with experts.

2.8.5 Demonstration

After development the artifact is demonstrated to show its use and functionality (Peffers et al., 2007). Various qualitative research approaches can be used to demonstrate the artifacts functioning such as an experiment, simulation or a case study (Babbie, 2010). This research required a case-study to provide in-depth examination of its usability and demonstrate the application of theory. Demonstration gives opportunity for feedback that can be further used to improve the artifact. The fictitious Archisurance organization is selected that provides a realistic context, that of a post-merger insurance company, that can adequately in-depth demonstrate the framework. The case-study is documented and explained in chapter 5.

2.8.6 Evaluation

Evaluation compares the results of the demonstration with the objectives of the solutions as specified earlier (Peffers et al., 2007). Hevner et al. (2004) describes numerous evaluation styles and evaluation methods. A demonstration studies an artifact in depth in the business environment and is categorized as an observational evaluation style. Evaluation also sees the artifact submitted to a panel of experts that predict the frameworks interaction within a specific imagined problem context. Experts are selected based on their background and/or knowledge in each (academic) field to build a convincing argument of the framework's utility. Evaluation concludes with an online and offline questionnaire among practitioners to collect and measure individual opinions. Evaluation is described in detail in chapter 6.

2.8.7 Communication

This thesis will be made public online in the University of Twente student thesis repository. Inline with the thesis requirements of the University of Twente this research will be presented in a colloquium, also available to the public, where offline copies of the thesis are handed out.

2.9 Research contribution

The proposed framework represents the main artifact of this research. The framework's significance is listed, classified on its main stakeholders, below.

2.9.1 Scientific contribution

The FEUD artifact described in this thesis integrates theories of enterprise architecture, decision-making, and investment valuation by building on risk management, capability and strategic investment theories. It provides a context for real option valuation in decision-making under uncertainty and extends EA with decision-making constructs. Rather than generic and theoretical suggestions it aims to provide a comprehensive context for further research on the area of decision-making in EA.

2.9.2 Executives

Executives are typically tasked with making strategic decisions but are often less involved with the details of EA. A communication gap was perceived between perspectives of executives and the enterprise architects that can lead to the misalignment in the EA (Rathnam, Johnsen, & Wen, 2004). Attempts have been made to express EA in terms of value but little literature exists that expresses the EA in terms of decisions (Saha, 2006). FEUD provides an integrated perspective on investments (decisions on investment options) and value holistically throughout the EA with the ambition to provide a basis to bridge perspectives.

2.9.3 Enterprise architects

Enterprise architects typically have functions that bridges executives, management and IT. Decisions are made on a strategic level that aim to establish a long-view (Schwartz, 1991) while this view is implemented by making tactical and operational decisions. An EAF creates the context for these decisions while the decision-making framework in this thesis underpins the actual decision. By viewing the EA as a series of decisions it facilitates improved communication with the executives and increases accountability. It further incorporates theories from a variety of EA (related) practices such as Enterprise/IT Governance, Capability Management/Planning and Risk Management into a single integrated process.

2.9.4 BiZZdesign

This research demonstrates how decisions and options can be modeled in Archimate and adds to Archimate's existing body of literature. It adds valuation tools that can be used in conjunction with existing BiZZdesign tools, i.e. Enterprise Architect, that valuate investments and flexibility or be adapted and included in its products.

Chapter 3

Theoretical framework

3.1 Enterprise Architecture Frameworks and Models

Enterprise Architecture Frameworks (EAFs) have been used to describe and discuss Enterprise Architecture (EA) in businesses since the 80s. Survey among IT executives, Luftman and Derksen (2012) indicate EAs to be among top concerns (Luftman & Derksen, 2012) with newer studies showing a shift of concern towards business and IT alignment (Kappelman, Mclean, Vess, & Gerhart, 2014), a target area of EA. The first to document and publish an EAF was J. Zachman in the IBM Systems Journal in 1987. Zachman, while working for IBM, created a two dimensional classification scheme for descriptive representations of an enterprise (Zachman, 1987). Various EAF's have been introduced since, some detailed in appendix D, and every consultancy (e.g. Gartner, Deloitte, Accenture, PWC) and many organizations (e.g. defense, governments etc.) now have their own position and methodology on EA. The need for EA originated from the need to bring organization to the growing lists of technology used in an enterprise. In the last decade focus has shifted from a more technological view to one that focuses on bringing business organization in coordination with technology. ISO/IEC 42010:2007 (ISO, IEC, & IEEE, 2011) defines architecture as "The fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution". The Open Group, although embracing the ISO definition of architecture also identifies two meanings depending on the context:

1. A formal description of a system or a detailed plan of the system at component level to guide its implementation

2. The structure of components, their interrelationships, and the principles and guidelines governing their design and evolution over time

The Open Group defines the enterprise as "any collection of organizations that has a common set of goals" and considers the enterprise as the system subject to architecture. An EAF therefore is defined as "a documentation structure for EA"(Zarvic & Wieringa, 2006). The following section and appendix D give an overview of some of the most used EAFs (Cameron & McMillan, 2013).

3.1.1 Zachman Framework

Table 3.1 depicts a taxonomy based on the Zachman EAF, updated since its publication in '87, it classifies artifacts on the intersection of six questions (What, Where, When, Why, Who and How) and five perspectives (Contextual, Conceptual, Logical, Physical and Detailed)(Zachman, 1987). The Zachman Framework can be seen as a taxonomy for organizing architectural artifacts that takes into account several levels and perspectives. When moving horizontally through the grid, different descriptions of the system from the same person's perspective are shown. Moving vertically shows a single focus from different perspectives. Zachman's EA provides several rules on how to effectively use the schema to help classify artifacts and detect problems. Three suggestions are made that can help the development of an EA classification based on Zachman's EA:

1. every architectural artifact should exist in one cell only. Ambiguity about this likely indicates an issue with the artifact itself
2. an architecture is only complete when every cell is complete. A cell is complete when it contains sufficient artifacts
3. Cells relate to adjacent cells in the same perspective (column)

Since John A. Zachman originally developed his taxonomy while working with IBM's Business System Planning (BSP) it did not include an EA process that describes the steps on how to create an EA using his schema, regardless it still remains one of the most popular frameworks. Some of its advantages include its comprehensiveness, simplicity and neutrality, however for it to become useful it must be complemented with elements such as a formal basis, process models, methods and/or tools (Iacob, Jonkers, Quartel, Franken, & Berg, 2012).

Table 3.1: Zachman EA Framework

	What	How	Where	Who	When	Why
Contextual	Material List	Process List	Business Locations List	Organizational Unit & Role List	Event List	Goal List
Conceptual	Entity Relationship Model	Process Model	Business Logistics Model	Work-flow Model	Event Model	Business Plan
Logical	Data Model Diagram	Process Diagram	Distributed Systems Diagram	Relationship Diagram	Event Diagram	Business Rule Diagram
Physical	Data Specification	Process Specification	Location Specification	Role Specification	Event Specification	Rule Specification
Detailed	Data Details	Process Details	Location Details	Role Details	Event Details	Rules Details

3.1.2 TOGAF

The Open Group Architecture Framework (TOGAF) has been under development since 1995 and was based on the Technical Architecture Framework for Information Management (TAFIM) from the US department of defense. TOGAF, since 2011 in its 9.1th incarnation, distinguishes four architecture domains:

1. Business Architecture: defines the business strategy, governance, organization, and key business processes.
2. Data Architecture: describes the structure of an organization's logical and physical data assets and data management resources
3. Application Architecture: provides a blueprint for the individual applications to be deployed, their interactions, and their relationships to the core business processes of the organization.

4. Technology Architecture: describes the logical software and hardware capabilities that are required to support the deployment of business, data and application services.

At the core of TOGAF lies its Architecture Development Model (ADM), their iterative, cyclical and tailorable process for establishing EA (The Open Group, 2011) shown in figure 3.1.

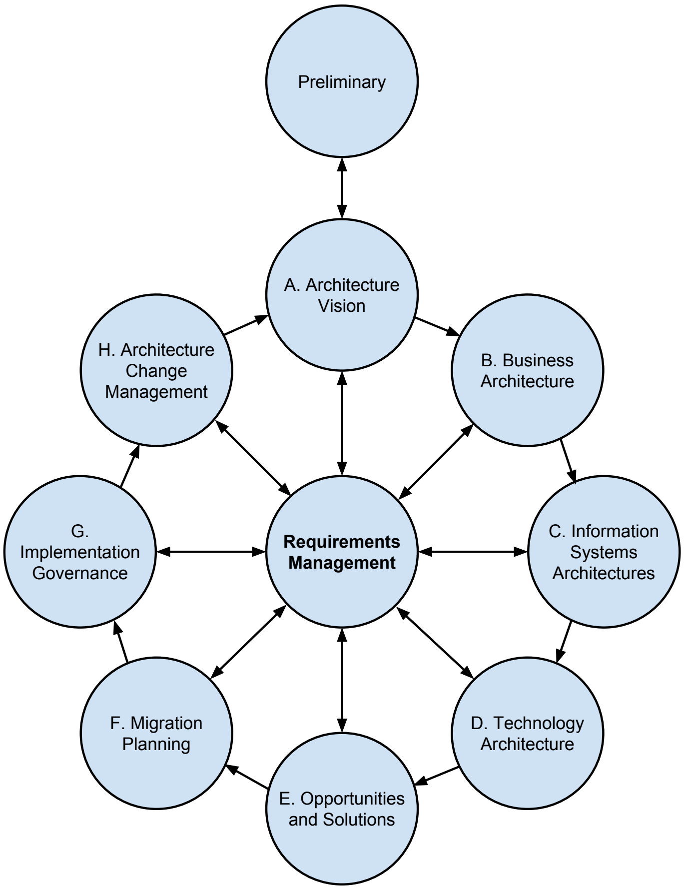


Figure 3.1: TOGAF ADM structure

- Preliminary phase: prepares the organization for EA and tailor the EAF to the specific needs.
- Phase A: Architecture Vision: identify the vision, scope, constraints and goals of the EA
- Phase B: Business Architecture: develop the business architecture target and baseline
- Phase C: Information System Architecture: develop the information systems architecture target and baseline
- Phase D: Technology Architecture: develop the technology architecture target and baseline
- Phase E: Opportunities & Solutions: perform an initial implementation planning: identify projects
- Phase F: Migration Planning: plans how to move from the baseline to target architectures
- Phase G: Implementation Governance: provide an architectural oversight of the implementation

- Phase H: Architecture Change Management: establish the procedures for managing change to the EA
- Requirements Management: continuously drive the ADM by a dynamic set of requirements. TOGAF does not mandate any specific tool or process but states what a successful requirements management process should achieve.

Key to the ADM is that it is iterative over the whole process, between the phases and within phases and only provides a generic model that can and should be tailored to specific needs and capabilities. Each phase can generate artifacts that in turn can match artifacts in the Zachman EAF. The Enterprise Continuum is a virtual repository for all the architecture assets (models, patterns, viewpoints and descriptions) of a company or relevant, available reference models and standards in the industry. Initially this will be an empty framework that will be filled during the execution of ADM cycles figure 3.2. It consists of the following architectures that increase in detail specific to the enterprise:

- Foundation Architectures: contains generic assets that provide a base for specialization and can be used by any organization.
- Common Systems Architectures: assets specific to a problem domain that can be relevant across a wide number of domains (e.g. a security architecture).
- Industry Architectures: integrates common systems components with industry-specific components (e.g. an Oil & Gas upstream reference architecture)
- Organization-Specific Architectures: architecture specific to an enterprise

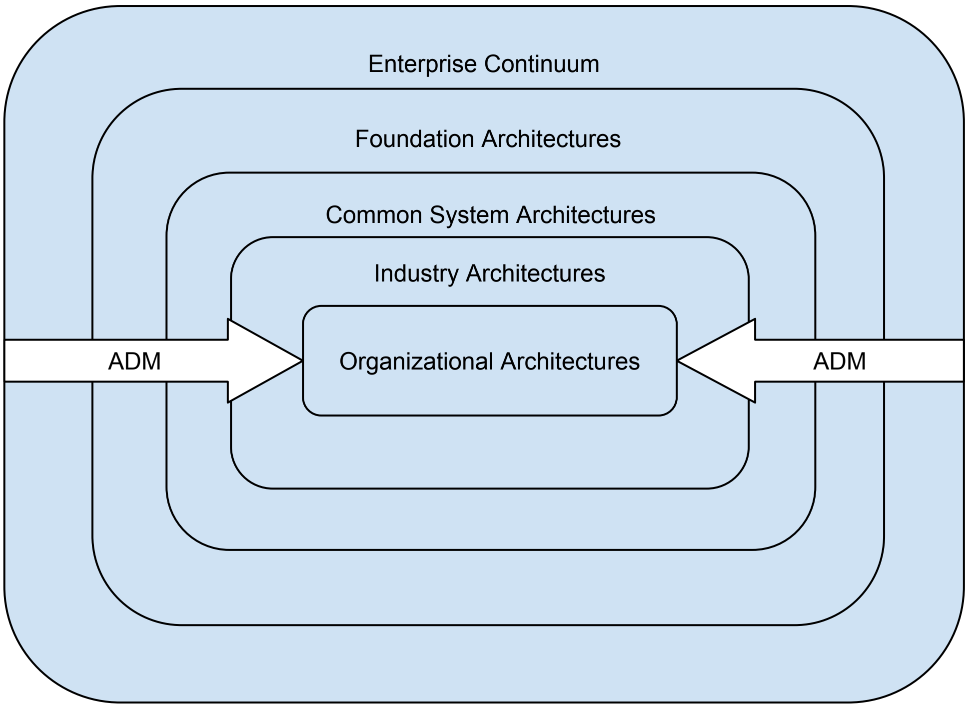


Figure 3.2: TOGAF ADM process

TOGAF further introduces 3 foundation architectures as reference models:

1. Technical Reference Model (TRM): a generic set of platform services that provides a taxonomy in which these platform services are divided into categories of like functionality. Provides a starting point or reference for an organization to develop own reference models.

2. Integrated Information Infrastructure Reference Mode (III-rf): a model for business and infrastructure applications with a specific aim to support the flow of information.c

3. Standards Information Base (SIB): a database that contains facts and help on information system standards that can be sourced from standards bodies (e.g. ISO or IEEE), or from authoritative standards makers (e.g. Internet Society), or from other consortia (e.g. World Wide Web consortium and Object Management Group).

3.1.3 Archimate

Archimate, an open standard, is an architectural modeling language created as part of a research project that involved Dutch research institutes, several large corporations and governmental institutions. It currently is the most widely accepted language for enterprise architecture, also the only 'complete' enterprise architecture modeling language that furthermore is endorsed by the Open Group for use with TOGAF.

Archimate Framework

The Archimate framework consists of layers and aspects as shown in figure 3.3 where the motivation column and implementation & migration layer are covered by Archimate extensions. The layers distinguish successive levels of abstraction:

1. Business layer: offers products and services to external customers realized by business processes

2. Application layer: supports the business layer with by services realized by application components

3. Technology layer: offers infrastructural services to applications realized by technology components

Aspects represent different concerns of the enterprise that need to be modeled. They can be categorized in the following types:

1. Active structure: elements and structure of elements that execute behavior on a passive structure element (e.g. actors)

2. Behavior: the action and structure of actions performed

3. Passive structure: objects on which behavior is performed

Since version 2 of Archimate two extensions have been added to the framework:

- Motivation: captures the context and reasoning behind the EA
- Implementation & Migration: supports program and project management

Relationships

Archimate contains a core set of relationships to connect elements in the framework mentioned in table 3.2, many of which have been adopted from existing standards such as composition, aggregation, association, and specialization from the Unified Modeling Language (UML) and others from business process modeling languages such as triggers. Figure 3.4 shows the relationships between elements from the different aspects (colors matching those of the framework) and figure 3.5 shows the relationship of the extensions to core elements.

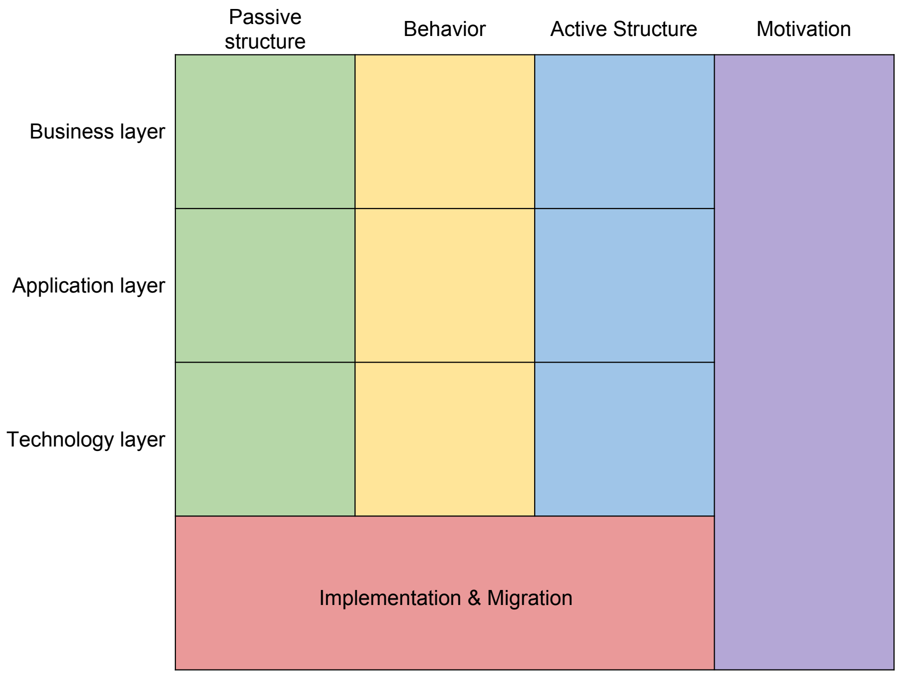


Figure 3.3: Archimate Framework

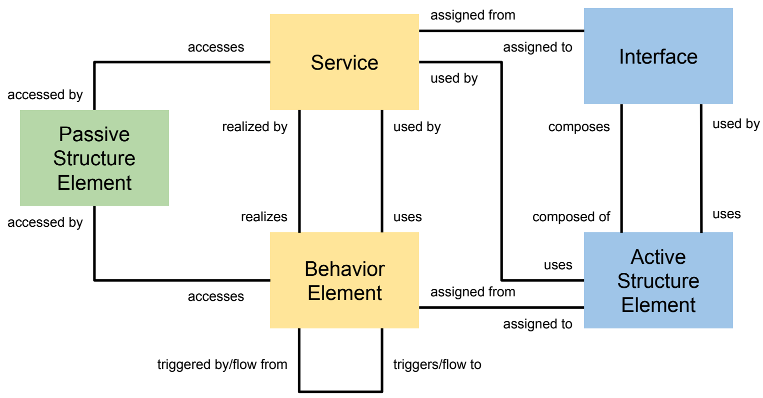


Figure 3.4: Archimate Core meta-model

Archimate and TOGAF

As shown in figure 3.6 the core abstraction layers modeled in Archimate (business, application and technology) can be mapped directly to Phase B, C, and D of the TOGAF ADM. The Archimate extensions language and analysis techniques support the other phases of TOGAF ADM and are the result of the extensive cooperation in the Open Group on both standards.

View points

Different from models such as the Zachman EA framework Archimate provides flexible viewpoints, taking definitions on viewpoints from the ISO/IEC 42010:2007, which focus on the relationship of elements in different perspectives rather than classifying and positioning the various descriptions into fixed viewpoints. A standard set of viewpoints are provided that each focus on a particular set of concerns. It defines a view as a part of an architecture description that addresses a set of related concerns and is addressed to a set of stakeholders. A viewpoint specifies a view and determines how you look at the view by selecting the concepts, models, analysis techniques and visualizations. Figure 3.7 along with table 3.3 and table 3.4

Table 3.2: Archimate relationships

Name	Description	Notation
Structural Relationships		
Association	relation between objects not covered by other more specific relationships	
Access	access of business or data object	
Used by	service usage or interface access	
Realization	link to more concrete entity	
Assignment	assign behavior to active element	
Aggregation	indicate that an object groups a number of objects	
Composition	indicate that an object is composed of one or more objects	
Dynamic Relationships		
Flow	describes the exchange or transfer of information or value	
Triggering	signifies a causal relationship	
Other Relationships		
Grouping	groups objects on a common characteristic	
Junction	connect relationships of the same type	
Specialization	indicates an object is a specialization of another type	

shows Archimate's categorization of the dimensions of purpose, level of abstraction along with examples of typical stakeholders possible and example artifacts.

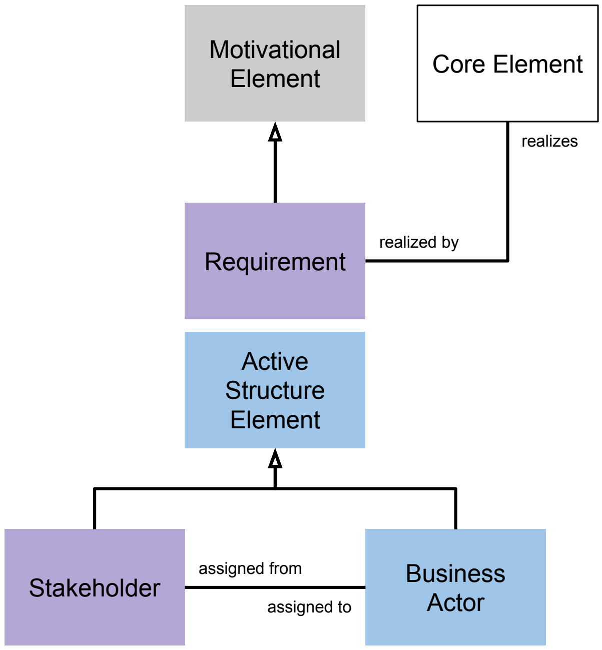


Figure 3.5: Archimate Motivation Extension meta-model

Table 3.3: Archimate Viewpoint types

Viewpoint type	Typical Stakeholders	Purpose	Examples
Designing	architect, software developer, business process designer	navigate, design, support design decisions, compare alternatives	UML diagram, BPMN diagram, flowchart, ER diagram
Deciding	manager, CIO, CEO	decision-making	cross-reference table, landscape map, list, report
Informing	employee, customer, others	explain, convince, obtain commitment	animation, cartoon, process illustration, chart

Table 3.4: Archimate Viewpoint layers

Abstraction	Typical Stakeholders	Purpose	Examples
Details	software engineer, process owner	design, manage	UML class diagram, BPMN process diagram
Coherence	operational managers	analyze dependencies, impact-of-change	view expressing relationships like “use”, “realize”, and “assign”
Overview	enterprise architect, CIO, CEO	change management	landscape map

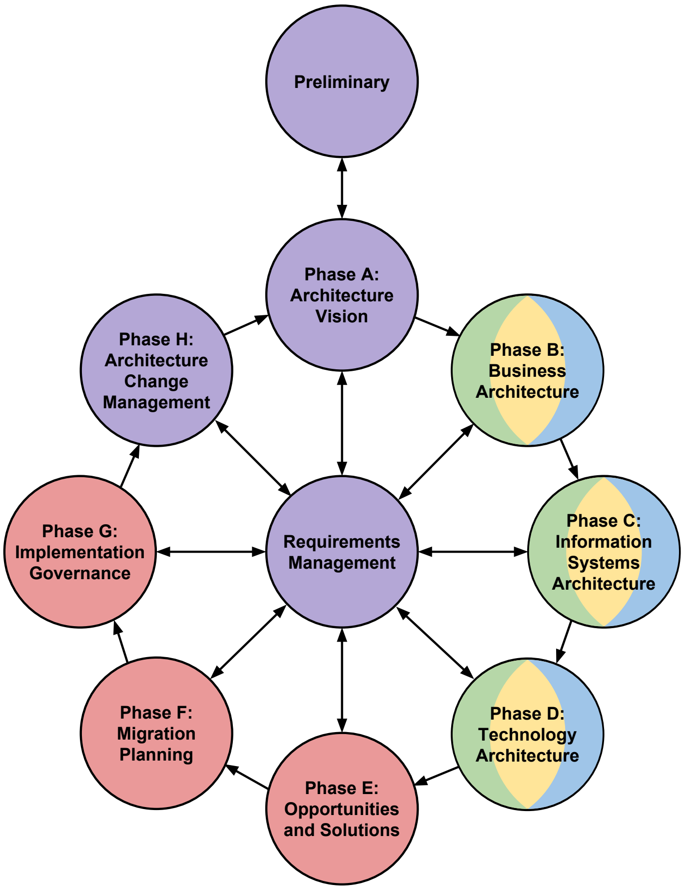


Figure 3.6: Archimate mapped to TOGAF ADM

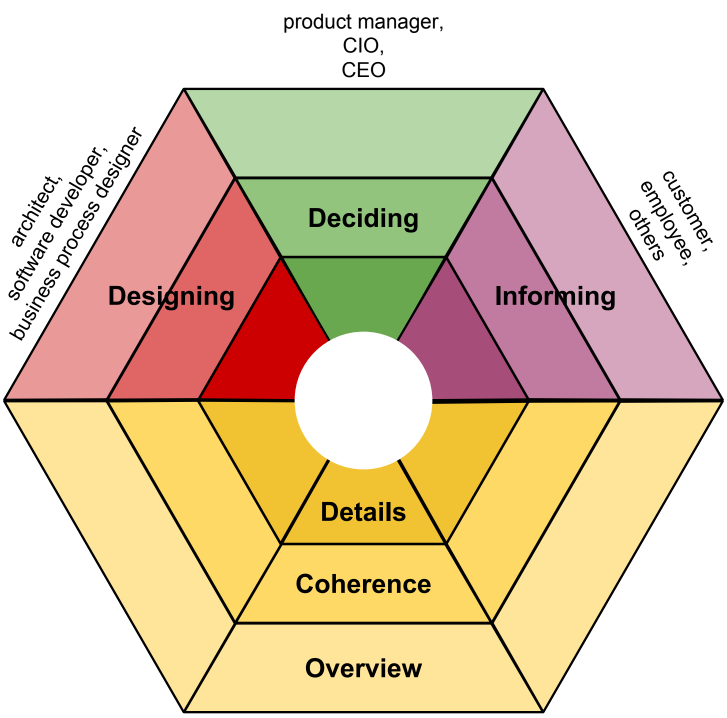


Figure 3.7: Archimate Viewpoints Classification

3.2 Financial Evaluation

Financial evaluation of a project or company analyses its profitability. The activities of a company can be seen as a collection or a succession of projects. The financial evaluation of projects typically involves the following basic financial inputs (Crundwell, 2008):

- Revenue. Revenue is the income that a company receives because of the project's activities.
- Cost. The value of money needed as overhead for or in operating a project. Operating costs are incurred directly in manufacturing or developing items such as labor, material and energy costs. These typically increase with the amount of production. Overhead costs are all other costs, such as administrative, sales and marketing.
- Taxes and royalties. Taxes represent the charges made by a government, such as income- and capital gains- tax. Royalties are additional charges for the use of natural resources.
- Capital expenditure (CapEx). The fixed capital required required as investment to buy or upgrade fixed assets such as property, equipment.
- Working capital. The net amount of money required for stock, debtors and creditors.

These inputs are used to establish the cash flows, the movement of money in or out of a company, a project or a financial product measured for a given period. They are used to calculate other parameters that give insight into financial performance. The cash flow in a period is calculated by subtracting costs, taxes and royalties from the revenues. A Net Cash Flow (NCF) determines cash inflows and outflows of an entire company and therefore shows changes in a company's cash balance. A Free Cash Flow (FCF) is the cash flow less the capital expenditure and the working capital requirement. It represents the net cash available and is often used to determine economic viability.

3.2.1 Forecasting value

Financial evaluation often forecasts cash flows to determine if a project justifies investment. A key principle in forecasting value is to account for the time value of money and the cost of capital.

- The time value of money principle states that money available now, at present time, is worth more than the same amount in the future due to a potential earning capacity. This potential earning capacity is created by having the money available to earn a return on investment, such as interest or dividends payments. Some of the reasons why this potential might not be realized can be due to inflation, risk and/or a preference for liquidity.
- Cost of capital is the minimum return investors expect for providing capital to a company. It sets the benchmark that a new project has to meet and is based on the time value of money and risk. It is often used as the discount rate to calculate Present Value (PV) from a Future Value (FV), see page 23 for more on discount rates.

Discounted Cash Flow (DCF)

A DCF analysis is a method to value a project, company or asset using the concept of time value of money. In a DCF future cash flows are estimated and discounted by using cost of capital to give their present values (PVs). A PV is calculated with equation (3.1), note that the discount rate is discussed in detail on page 23.

$$\begin{aligned} PV &= \frac{FV}{(1+i)^n} \\ \text{where } FV &= \text{future value} \\ i &= \text{discount rate} \\ n &= \text{number of periods} \end{aligned} \tag{3.1}$$

NPV Net Present Value (NPV), typically calculated in a DCF analysis, is the sum of the present values (PVs) of incoming and outgoing cash flows in a period of time, see formula equation (3.2). NPV is often used as a simple measure to determine if an investment will result in net profit when it has a positive NPV or a loss with a negative NPV.

$$\begin{aligned} NPV &= \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t} \\ \text{where } N &= \text{total number of periods} \\ CF_t &= \text{cash flow at time t} \\ i &= \text{discount interest rate} \\ t &= \text{time of the cash flow} \end{aligned} \tag{3.2}$$

IRR The Internal Rate of Return (IRR) is often used to evaluate the desirability of investments. The IRR can be calculating using formula equation (3.2) by determining the discount rate where the NPV equals to zero, see equation (3.3).

$$\begin{aligned} NPV &= \sum_{t=0}^{N} \frac{CF_t}{(1+IRR)^t} = 0 \\ \text{where } N &= \text{total number of periods} \\ CF_t &= \text{cash flow at time t} \\ IRR &= \text{discount interest rate} \\ t &= \text{time of the cash flow} \end{aligned} \tag{3.3}$$

A higher IRR indicates a higher desirability of an investment. An investment is considered acceptable if its IRR is greater than the established cost of capital, the closer the IRR is to the actual cost of capital the riskier the investment. Software such as Mathworks Matlab's financial toolbox, R's financial packages, or Microsoft Excel can help approximate the IRR which represents a polynomial problem of finding roots. Excel uses an iterative technique that starts with a guess (default 10%) and cycles the calculation until a 0.00001% accurate result is found.

Discount Rate The discount rate is the interest rate used to determine the present value, considering the time value of money, from future cash flows. The discount rate for a project depends for a great deal on the risks involved. If an investment does not have any uncertainty associated with its cash flows the appropriate discount rate is a risk-free rate. A risk-free rate thus also represents the bare minimum return an investor expects for any investment regardless of its risk. In practice the interest rate of a risk-free bond issued by a 'trusted' government or agency is often chosen as the risk-free rate, its risks of a default are considered negligible. Considering the two types of risk, private and market risk, literature argues using to use a risk-free rate if a cash flow stream is strictly subject to private risk. In practice however it's difficult to strictly separate private from market risks and such investments often require capital that most organizations pay a cost to obtain (Kodukula & Papudesu, 2006). Because assets in a corporation are typically financed by either debt or equity a common discounting measure used is the average cost of these capital sources, weighted by its use in the given situation known as the Weighted Average Cost of Capital or WACC (Koller, Goedhart, & Wessels, 2010).

Cost of Equity The cost of equity, i.e. the cost of a company to maintain a share price that is acceptable to its investors is often calculated using the Capital Asset Pricing Model (CAPM) where the cost of equity (rE) is described in formula equation (3.4).

$$\begin{aligned} rE &= rf + \beta(rM - rf) \\ \text{where } rf &= \text{risk free rate} \\ \beta &= \text{measure of investment volatility} \\ rM &= \text{market rate} \end{aligned} \tag{3.4}$$

Risk free rate The risk free rate is the previously discussed risk-free rate that would be obtained through an investment in securities 'without risk' such as long-term treasury bond rates of a creditworthy country.

Beta measure of investment volatility A beta represents a measure of the investments volatility in relation to the market. A beta of one means its volatility is equal to the market, whereas an investment with higher volatility has a beta above one and an investment with lower volatility below one. A high beta investment, and thus highly volatile, is considered riskier. Betas capture systematic risks, which are the risks that affect the overall market and can't be mitigated through diversification. Betas come in levered and unlevered form. A levered beta contains the effects of the capital structure (see below) while an unlevered beta does not. Levered betas for public companies can be obtained from a number of online sources. These betas can be either historical or predicted. Historic betas are based on a company's trading history in a period (often 60 months). A predicted beta, also referred to as a 'fundamental beta' takes various various fundamental risk factors such as the company size, yield, price/earning ratio, industry exposure, volatility, momentum and those risks that could be found through a PESTLE analysis as explained in section 3.6.1. Predicted betas can also be estimated by unlevering the levered predicted beta of a comparable company and then re-lever the average unlevered predicted betas with the capital structure of the current company (inverse of the unlever formula with an estimated debt and equity of target company) equation (3.5). Private companies can use comparable public companies to estimate their historic and predicted betas by using the re-lever formula to update the beta for their own capital structure after unlevering the comparable betas. More sophisticated methods exist in finance to perform beta estimations in both various contexts and for various conditions (Damodaran, 2002; Fernandez, 2006).

$$\begin{aligned} \beta u &= \frac{\beta l}{(1 + (1 - Tc) * (\frac{D}{E}))} \\ \text{where } \beta l &= \text{levered beta} \\ \beta u &= \text{unlevered beta} \\ Tc &= \text{corporate tax rate} \\ D &= \text{debt} \\ E &= \text{equity} \end{aligned} \tag{3.5}$$

Equity market risk premium The equity market risk premium $(rM - rf)$ which is the difference (a premium) of expected returns on an investment, a market rate (rM) over the risk-free rate (rf) to compensate investors for investing with higher risks compared to risk-free securities.

Cost of debt (after-tax) The 'cost of debt' (rD) is the interest paid on the company's debt. This is either the market rate or an estimated rate. Because of the tax deductions available on paid interest, the cost of debt is the interest paid without the tax savings resulting from the tax-deduction, hence the full formula is:

$$\begin{aligned} & rD * (1 - Tc) \\ \text{where } rD &= \text{cost of debt} \\ Tc &= \text{corporate tax rate} \end{aligned} \tag{3.6}$$

Capital structure Capital structure describes how a company finances its assets. The WACC is based on the proportion of debt (D) and equity (E) in the company. The proportion of debt $\left(\frac{D}{V}\right)$, a ratio that compares a company's debt (D) to the company's total value (V) consisting of its equity (E) + debt (D). The proportion of equity $\left(\frac{E}{V}\right)$ is a ratio comparing the company's equity (E) to the company's total value (V) consisting of its $equity(E) + debt(D)$.

Weighted Average Cost of Capital WACC, represented by formula equation (3.7), is a mix of the above capital structure functions and the cost of equity and debt functions.

$$\begin{aligned} WACC &= rD * (1 - Tc) * (\frac{D}{V}) + rE * (\frac{E}{V}) \\ \text{where } rD &= \text{cost of debt} \\ Tc &= \text{corporate tax rate} \\ \frac{D}{V} &= \text{proportion of debt} \\ rE &= \text{cost of equity} \\ \frac{E}{V} &= \text{proportion of equity} \end{aligned} \tag{3.7}$$

DCF example To further illustrate table 3.5 shows an example of a DCF. Notice the cash outflow in total costs and cash inflow in revenue being discounted as PV. The PV at time 1 in 2015 with a discount rate, based on a WACC, of 13% calculated using formula equation (3.1) is:

$$PV_1 = \frac{FV}{(1+i)^n} = \frac{-10.50}{(1+13\%)^1} = -9.29\ (\$M),$$

The NPV for this company calculated using formula equation (3.2) for the DCF therefore is:

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t} = \frac{-5.00}{(1+13\%)^0} + \frac{-10.5}{(1+13\%)^1} + ... + \frac{13.30}{(1+13\%)^7} = 3.95\ (\$M)$$

Using only the DCF to financially evaluate this project would normally lead to an investment as the project's NPV is positive by 3.95 $(\$M)$ and the approximated IRR is slightly higher as the estimated discount rate, i.e. 13.04% versus 13.00%.

3.3 Making Decisions

Decision making is the process of making a choice. Making decisions is not trivial, even small decisions are subject to cognitive biases and fallacies, as studied extensively in psychology and behavioral economics (Tiwana, Jijie, Keil, & Ahluwalia, 2007). Literature traditionally recognizes the following main decision making methods (Payne, Bettman, & Johnson, 1986; Rothrock & Yin, 2008):

Table 3.5: Discounted Cash Flow Example

Year	2014	2015	2016	2017	2018	2019	2020	2021
Period	0	1	2	3	4	5	6	7
Initial costs ($M)	5.00							
Equipment costs ($M)		2.50	1.00	0.50	0.30	0.20	0.20	0.10
Employment costs ($M)		3.00	2.00	3.00	2.00	1.50	1.50	1.50
Contractor costs ($M)		5.00	2.00	0.50	0.20	0.20	0.10	0.10
Total costs ($M)	5.00	10.50	5.00	4.00	2.50	1.90	1.80	1.70
Revenue ($M)				3.00	9.00	10.00	12.00	15.00
Future cash flow ($M)	(5.00)	(10.50)	(5.00)	(1.00)	6.50	8.10	10.20	13.30
Present value ($M)	(5.00)	(9.29)	(3.92)	(0.69)	3.99	4.40	4.90	5.65
Discount rate	13.00%							
Net present value ($M)	3.95							
Internal rate of return	13.04%							

1. Compensatory decisions are rational decisions evaluated on on a full set of weighted attributes. In compensatory decisions a low preference on some attributes can be compensated by a high preference on other attributes.

2. Noncompensatory decisions evaluate decision options on an incomplete set of attributes through heuristics. Low preference on attributes of high relevance cannot be compensated by high scores on attributes of lower relevance.

Based on these types Payne et al. and Rothrock and Yin identify the following decision making strategies (Payne et al., 1986; Rothrock & Yin, 2008):

Compensatory strategy

- Weighted additive (WADD) considers the values of each alternative on all relevant weighted attributes. Using a WADD strategy the alternative with the highest sum of attribute value times attribute weight will be selected.

- Equalweight (EQW) selects the alternative with the highest sum of attribute values without considering attribute weights.

Noncompensatory strategy:

- Conjunctive decision making strategy eliminates options that fail to meet a minimum value on each attribute.

- Disjunctive decision making strategy selects an option based on maximum values for a chosen criteria on attributes.

- Elimination By Aspects (EBA) starts by selecting the most important attribute and its cutoff level. All alternatives with values for this attribute lower as the cutoff level are eliminated. The next step selects the second most important attribute, and so on until only one alternative remains.

- Majority of Confirming Dimensions (MCD) strategy involves comparing pairs of options. The values for each attribute of the two options are compared and the option with the highest values across all attributes is retained and then compared with the next option.
- Satisficing (SAT) strategy, compares the value of each attribute of an alternative to a predefined cutoff level. Alternatives with attributes below this cutoff are rejected while the first alternative that meets all cutoffs is selected. If no alternative can be selected the cutoff levels can be lowered and each alternative re-evaluated.
- Lexicographic (LEX) strategy identifies the most important attribute and the option with the highest value on this option is selected. In case of a draw, the second most important option between remaining options is selected and compared and so on until the draw is resolved.

3.3.1 Decision making in EA

Selecting a decision making method often depends on method aggregation preferences by decision makers and is not restricted to a single criterion (Lopes & Almeida, 2013). EA is complex and involves many decisions, by many persons, under time pressure, and often with great uncertainty. Ample academic literature exists on decision making strategies in the context of portfolio selection and the context of project prioritization (Almeida & Duarte, 2011), decision making strategies used in EAFs however remain relatively unresearched. A complete EA decision making framework should manage EA decisions by providing both a transparent and repeatable decision process for use in EAFs as well as a decision modeling language. Currently EA modeling languages do not provide support to capture the design rationale behind EA decisions which can lead to 'knowledge vaporization' (Jansen & Bosch, 2005). Plataniotis, Kinderen, and Proper propose an Archimate viewpoint that captures this decision making rationale (Plataniotis et al., 2013). The viewpoint as shown in 3.8 contains the following elements:

- Decision-Making Strategy: captures the used compensatory or noncompensatory strategy/strategies used to evaluate the alternatives.
- Strategy rationale: the rationale for the decision strategy that was selected in the evaluation process.
- Criterion: criteria used in the decision strategy.
- Value: the value assigned to the criteria.
- Weight: the importance of the criteria.
- EA Decision: the actual EA decision made after the decision process.
- Alternative: the available choices under evaluation.

3.3.2 Governance

Corporate governance is the system by which corporations are controlled and directed, how rights and responsibilities are distributed among stakeholders (executives, shareholders, creditors, auditors, etc.) and includes procedures and the rules for making decisions that affect the corporation (Shailer & Australian National University, 2004). IT Governance is a subset that focuses on IT or what is affected by IT. Van Grembergen, De Haes, and Guldentops define IT Governance as "an integral part of enterprise governance and consists of the leadership and organization structures and processes that ensure that the organizations IT sustains and

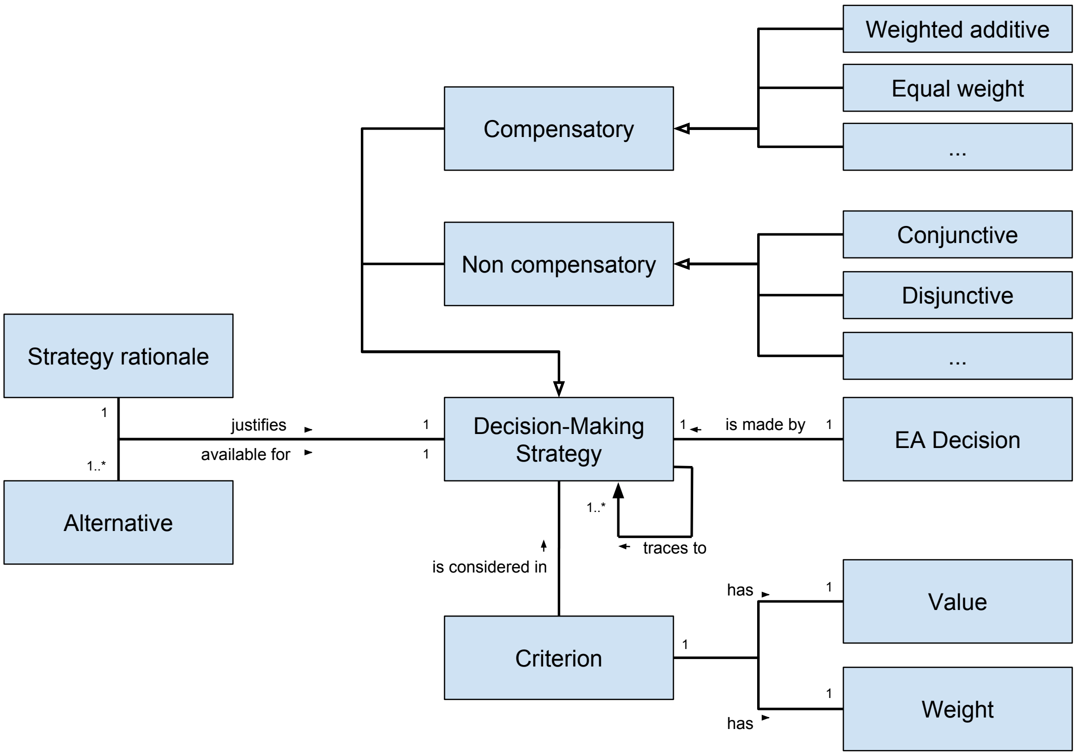


Figure 3.8: Metamodel of Decision Making Strategy viewpoint

extends the organizations strategies and objectives" (Van Grembergen et al., 2004). Simonsson and Johnson shows however that no single shared definition is used in literature and indicates IT Governance is "basically about IT decision-making" and therefore suggest the following definition "the preparation for, making of and implementation of decisions regarding goals, processes, people and technology on a tactical and strategic level". If EA is viewed as a decision making process, IT Governance can be viewed as the system that ensures an EA decision making system is effective and transparent. It should define the responsibilities of who can make a decision, define who is responsible for its consequences, define controls that validate the decision-making and ensure the decisions are ultimately in-line with the enterprise strategy and all applicable laws. The accounting scandals in the '90s and the beginning of this century (e.g. Enron, Tyco, and Worldcom) saw the passing of the Sarbanes-Oxley (SOX) act to protect investors. SOX provides two key provisions:

- section 302 which mandates that all senior management certifies the accuracy of a reported financial statement.
- section 404 which requires that management and auditors establish internal controls and reporting methods on the adequacy of those controls.

Compliance to SOX became a requirement in the U.S. for public companies which fueled the need for governance in all corporate areas (e.g. financial governance, IT governance). Many governance frameworks exist; the most used IT governance framework currently is COBIT.

COBIT

ISACA is the international association that created the Control Objectives for Information and Related Technology (COBIT) framework, a standard for IT Governance and designed to be consistent with the COSO framework setup by the Threadway Commission in a response to SEC's (U.S. Securities and Exchange Commission) SOX regulations. Its goal is to improve internal business controls and increase the reliability of financial reporting. Section 302 of SOX makes executives personally liable and section 404 advocates the use of a structured framework, such as COBIT, to implement controls. COBIT structures controls in a set of domains:

- Planning & Organization
- Acquisition & Implementation
- Delivery & Support
- Monitoring

Each domain has a set of processes, a total of 34 in COBIT version 4.1, that contain critical success factors, key goal and performance indicators and 6 levels of maturity. Several mappings of COBIT controls to COSO objectives exist, among those created by ISACA (Taylor, 2008). With its primary objective of establishing rigorous controls, COBIT can be used next to other frameworks, in fact ISACA now provides mapping documentation between COBIT and several frameworks including ISO/IEC 27002 and TOGAF (Hardy & Hesch, 2008). A COBIT implementation can support the EA efforts by establishing IT governance structures that control and direct the EA decision-making.

3.3.3 EA decision making through financial evaluation

Financial evaluation, as discussed in section 3.2, can analyze the profitability of investments in projects. Accordingly, it supports decision making in EA projects but also between or on EA projects, where the most profitable projects are selected for investment in favor of those less profitable. Capital investment projects can have a more strategic or operational focus (Alkaraan & Northcott, 2006). Strategic investments typically deal with bigger scale, longer time periods and are more difficult to quantify an outcome for. Numerous financial analysis methods, used often in operational investment valuation and that include both qualitative and quantitative factors, have been integrated with strategic investment appraisal methods. Financial analysis methods include valuation of the NPV and IRR measures described earlier in section 3.2.1. Alkaraan and Northcott give an overview on the following key strategic-investment appraisal methods that are put in context of EA decision-making.

The balanced scorecard method

Originating in the Harvard Business School, Kaplan and Norton introduced balanced scorecards in 1992 for use in strategic management, the administering process that continuously formulates, adjusts and implements strategies in an enterprise, that has since seen widespread adoption in the industry. The balanced scorecard (BSC), see figure 3.9, measures performance from criteria measured in four perspectives: financial, internal business processes, learning and growth, and customer. Scholars have suggested its usefulness in strategic capital investment decision-making (Alkaraan & Northcott, 2006). Schelp and Stutz (2007) propose the use of a BSC based approach to evaluate EA value and Van Grembergen and De Haes (2005) propose an IT governance BSC based on his earlier work on IT BSCs (Van Grembergen, 1997). Little research however exists on IT BSCs use in practice.

Value chain analysis method

Value chain analysis helps enterprises identify their key value-creating activities to support formulation of strategies that have the potential of creating a sustainable competitive advantage (Porter, 1985). Figure 3.10 gives an overview of Porter's value chain. Research suggests it

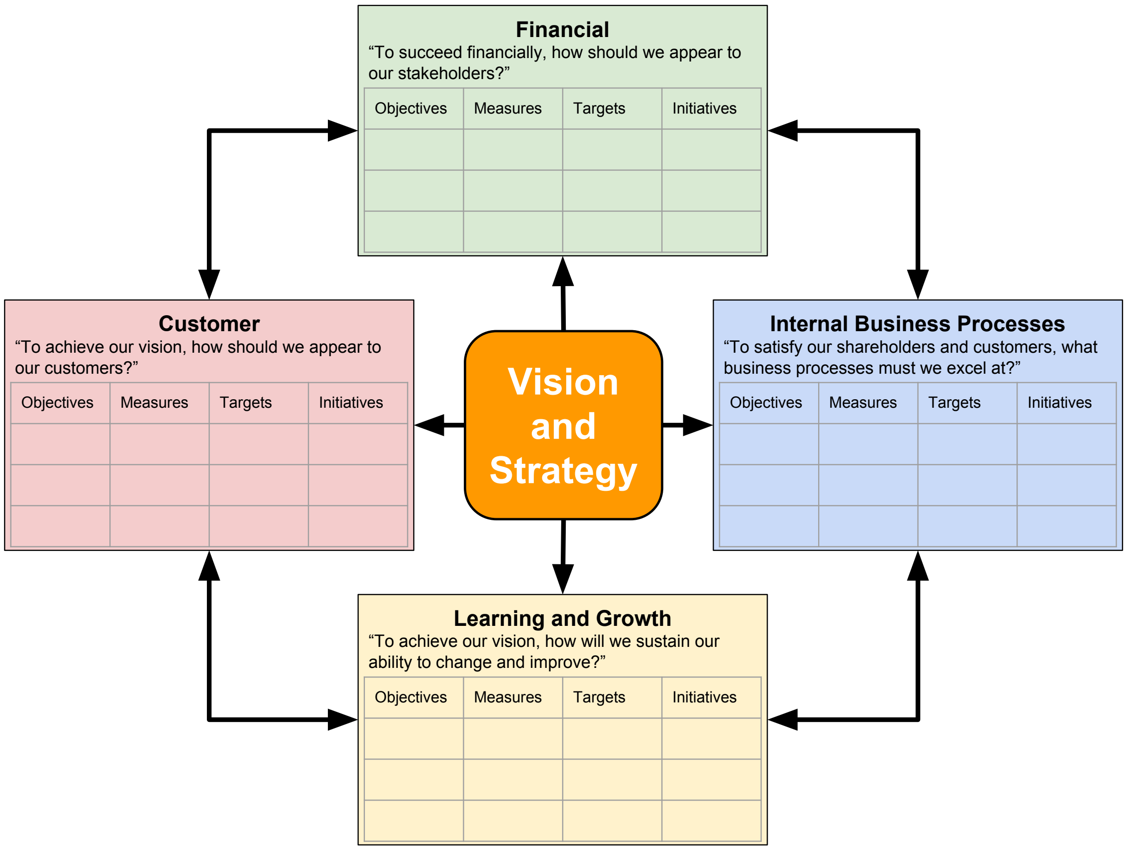


Figure 3.9: Kaplan and Norton's Balanced Scorecard

has the potential to inform decision makers during their strategic capital investment decision-making (Alkaraan & Northcott, 2006). Not much academic literature exists on the use and effects of value chain analysis in the context of EA. Its use has been restricted as a supportive tool in the strategy dimension.

Benchmarking method

Benchmarking compares the enterprise to the best practices of other comparable companies in the industry. This allows an organization to develop plans to improve or adapt specific best practices with the aim to increase their performance. To support benchmarking in EA, maturity models exist that help measure an organizations capability on various EA best practices. An example of such a maturity framework is the US Government General Accounting Office's Enterprise Architecture Management Maturity Framework (EAMMF) (Government Accountability Office, 2010).

Technology roadmapping method

Technology roadmapping is a structured, typically graphical, approach to explore and communicate the relationships between products and technologies in evolving and developing markets over time (Phaal, 2004). Technology roadmapping can help foresee and understand future technology trends and act as a decision making support tool. It explicitly integrates technological considerations into a business strategy and forecasts both on dimension of time. Changes in technological trends can force an organization to adapt and implement a response by performing EA transformations. As such technology roadmapping complements strategic EA decision making. Some practitioner guides and tools (e.g. Corso's extensions for TOGAF

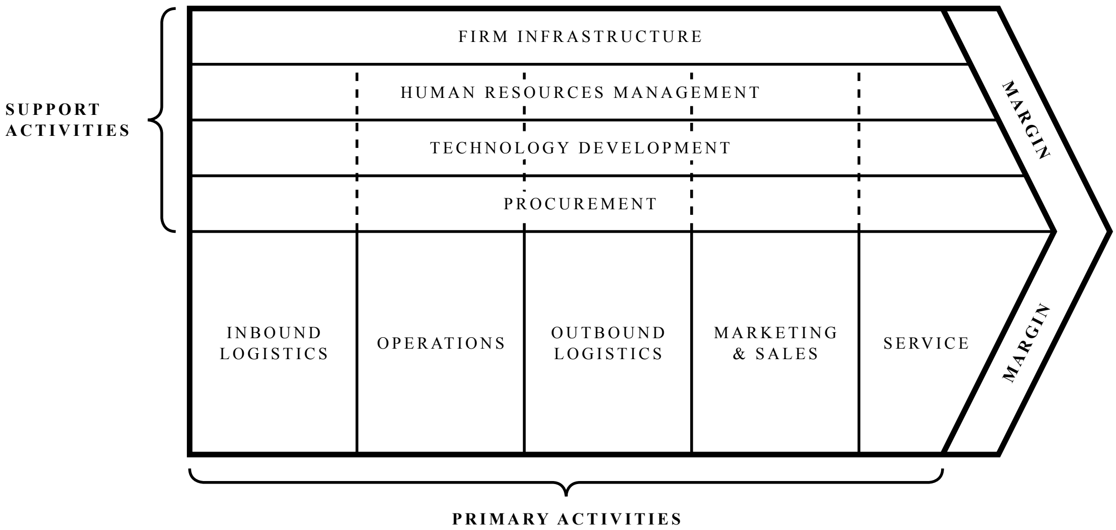


Figure 3.10: Porter's Value Chain

and Archimate (Owen, 2013)) exist for existing EA frameworks such as TOGAF. Empirical validation of these methods in academic literature remains scarce.

Real Options Valuation method

ROV, described in detail in section 3.8, supports the valuation of future flexibility in decision making. Instead of a fixed course calculation, such as investments in a DCF analysis, options for flexibility are identified and evaluated. By investing in options a capital project gains the ability to respond to risks by execution of the option to mitigate these when this makes financial sense. ROs have been widely advocated by academics for their use in strategic investment decision making (Teoh & Sheblé, 2007; Hilhorst, Smits, & Heck, 2005; Ang & Chai, 2010; Mun, 2002, 2006; Triantis & Borison, 2001; Copeland & Antikarov, 2003), however research on its actual use and validation on its usefulness currently remains empirically thin (MacDougall & Pike, 2003; Alkaraan & Northcott, 2006). Several different option pricing models (OPMs) can be used to valuate real options. The most popular are the binomial models, originally developed by Cox, Ross, and Rubinstein for discrete-time option valuation (Cox et al., 1979) and based on the influential work in Black and Scholes (1973) and extensions by Robert Merton in the same year (Merton, 1973). Criticism of ROV on IT investments includes the use of OPMs despite their critical assumptions (Ullrich, 2013; Borison, 2005), its applicability on non-financial assets and on its calculation mechanics (Borison, 2005). The use of ROs in EAFs has been limited mostly to the support of strategic decision making. Only a limited number of authors have researched the use of ROV holistically in the context of EA decision making (Mikaelian, 2009; Saha, 2006; Olagbemiro, 2008).

3.4 Uncertainty

In his 1921 classic, *Risk, Uncertainty and Profit*, University of Chicago economist Knight recognizes uncertainty as the occurrence of events with an immeasurable probability to set it apart from risk which he characterized as events with a knowable probability. In other words, based on Michael J. Mauboussin's (Mauboussin, 2006), uncertainty can be defined as the future events we don't know will happen and we don't know the probability distribution of, while risks are future events we don't know will happen but for which we do know the probability distribution. This classification has lead to discussion and uncertainty is defined in subtly different ways among different industries and academic fields. It comes at no surprise that EA transitions typically deal with large amounts of uncertainty due to the increasingly fast pace of business change required to stay competitive, the involved complexity and reliance on IT, the state of maturity and change within both the enterprise its IT and IT in general. Studies in 1999 already indicated that as much as 26% of all software projects failed, with 46% running over budget and 33% delivering significant less functionality as promised (Reel, 1999). EA efforts, as a 2008 survey for the Rotterdam University (Roeleven, 2010) indicates, do not achieve the expected results in 66% of the EA projects. Plenty practical causes for failure have been researched by Gartner (Pettey & Meulen, 2009) and others (Roeleven, 2010), that include issues such as having a lack of strategic-alignment, insufficient stakeholder/executive commitment, and a wrong governance structure. An often underlying cause to these problems is an inability to effectively respond to uncertainty. Uncertainties can be classified by their source of origin. Weck, Eckert, and Clarkson identify endogenous uncertainties, those originating within an organization and exogenous uncertainties, those originating from external sources (Weck et al., 2007).

3.5 Capability

Capability, the quality of being efficient and competent, was first put in a framework by the Carnegie Mellon University in their Capability Maturity Model (CMM) (CMMI Product Team, 2010). Published as a book by the Software Engineering Institute (SEI) in 1995 it has since become the best known maturity model for software development and is used extensively in projects worldwide. A maturity model describes a framework to assess and help improve, for a specific area of interest, the sophistication of activities in this area. EA capability maturity models (EA-CMMs) and EA as a capability, most of them based on SEI's CMM, have been proposed for EA in the industry, however currently with limited academic validation. The generic properties are discussed first before examples of existing of EA-CMMs are given.

3.5.1 Model type

Maturity models can be categorized broadly by two different purposes:

1. assessment
2. development

Normative models intend to support assessment with the target of certification. Examples include the ISO models that focus on certifying an organization to establish and improve a desired external appearance. Development models provide the tools and guidance to implement best practices and help streamline business processes with the ultimate goal of positively affecting business results. Organizations often select maturity models that not only enables assessment but also provides guidance for improvement: a hybrid development/assessment model gives such guidance and support.

3.5.2 Model architecture

Maturity models exists in two main representations: staged and continuous. A staged representation measures maturity levels for process improvement that apply to an organization's overall maturity. Here predefined sets of process areas define an improvement path for an organization. This means that to reach a certain level the entire organization requires to successfully have achieved maturity of all key areas on lower levels. In a continuous representation capability is used to measure process improvement. Capability levels apply to an organization's process-improvement achievement for each process area.

3.5.3 Model units

Maturity models typically measure maturity on two dimensions:

1. maturity levels
2. maturity areas

Maturity levels

CMM distinguishes 5 levels of maturity that are incorporated directly into the model:

1. initial
2. managed
3. defined
4. quantitatively managed
5. optimizing

At the lowest maturity level processes are ad hoc and chaotic and an organization is characterized by a tendency to rely on the skill of a few people. A managed maturity has planned processes that are executed in accordance to policy and with basic control and visibility. A managed organization starts looking at its processes as the main driver behind its performance. On a defined maturity an organization increases the scope of its process definition to an organizational level. Processes are also defined more rigorously and each instance of a process (i.e. a particular project) receives a tailored process from the organization's set of standard processes along predefined tailoring guidelines. Quantitatively Managed, maturity level 4, establish quantitative objectives for quality and process performance and use them as criteria in managing projects. At the highest level of maturity an organization continually improves its processes, based on quantitative understanding of its business objectives and performance needs. It focuses on managing and improving organizational performance on an organizational level (across projects) to identify shortfalls and gaps in performance.

Maturity areas

Maturity levels are measured for certain maturity areas or domains. CMM for example measures maturity for four areas: project management, process management, engineering and support. Defining maturity areas is not trivial and requires validation to ensure sufficient applicability and generalization. For each maturity area a group of practices, process areas, are defined that when satisfied collectively improve an organization's maturity.

3.5.4 EA Capability Maturity Frameworks

Capability Maturity Model Integration

CMMI, the successor of the CMM model, was created to "integrate traditionally separate organizational functions, set process improvement goals and priorities, provide guidance for quality processes, and provide a point of reference for appraising current processes" (CMMI Product Team, 2010). It uses the same maturity levels but provides support for three areas of process improvement:

1. CMMI-DEV supports product and service development. It gives guidance for managing, measuring and monitoring solution development processes.

2. CMMI-ACQ supports product and service acquisition. It gives guidance to enable informed and decisive acquisitions.

3. CMMI-SVC supports service establishment, service management and service delivery. It guides service delivery both within organizations and to external customers and partners.

These areas cover aspects of an EA but assessing EA capabilities is not its intended use.

DoC ACMM

The U.S. Department of Commerce (DOC) developed the Architecture Capability Maturity Model (ACMM) initially to self-assess maturity. It is freely available from the DOC website and comes recommended by the Open Group for use with TOGAF. It uses six levels of maturity, similar to those of CMM, and assesses maturity on these nine characteristics:

- IT architecture process
- IT architecture development
- Business linkage
- Senior management involvement
- Operating unit participation
- Architecture communication
- IT security
- Architecture governance
- IT investment and acquisition strategy

ITScore for EA by Gartner

ITScore by Gartner assesses maturity for EA at five levels, again similar to those of CMM, and based on eight major dimensions of an EA practice, figure 3.11 shows an example by Sullivan (2011) qthat broadly follows these dimensions and gives an interpretation for each level. ITScore is a closed model for use by Garner's clients and as such does not have the same amount of usage of open frameworks. It is characterized by its light-weight and pragmatic approach but does not have the academic background and rigor most of the other frameworks have.

Description	No formal EA program is in place	An EA program is in place, but is working poorly due to weaknesses in several dimensions of maturity	An EA program is in place and delivering value to the business	The EA program is delivering value and is repeatable	This level indicates that a company has achieved a high level of maturity
Stakeholders Support	Infrastructure managers and Application developers actively participate but CIO / Director of IT is still not sure of the value of EA.	CIO / Director of IT is more actively getting involved and is beginning to see the value of EA. Project/Program Managers start to ask EA for assistance. Some Business Unit Manager have engaged in EA projects	Project/Program Managers now actively participate. Business Unit Manager have requested EA projects. Senior Corporate Management become more aware of EA	Senior Corporate Management actively engage with EA	All Stakeholders actively participate in EA
Communication	EA communication activities are ad-hoc and generic	Some EA communications are planned and tailored to specific stakeholder needs	Most EA communications are planned and tailored to specific stakeholder needs	All EA communications are planned and are tailored to specific stakeholder needs	
Team Resources	Some people have been assigned enterprise architecture as their primary responsibility. Some team members that have received basic EA training. Basic tools such as MS Office are used to document the EA	For some projects, Subject matter experts have been recruited temporarily onto the EA virtual team to participate in developing the EA. Most EA team members that have received basic EA training. Basic tools such as MS Office are used to document the EA	Subject matter experts used on most EA projects. Some Long-term EA team members that have received advanced EA training, some are certified. A specialized EA tool is used to document the EA	Subject matter experts used on all projects. All EA Team Members are certified in EA framework. A specialized EA tool is used to document the EA with some integration to other related tools	Enterprise architects that are certified through an internally approved certification scheme. Specialized EA tools are well integrated with other related tools (e.g., CMDB, BPM)
EA Development Method	No EA Development process or EA Governance defined. Majority of Architecture development decisions are made by IT	At least one cycle of the EA development process has been completed. Some Architecture development decisions are made jointly by IT and the business (i.e., duopoly)	An EA development process has been defined or adopted. A subset of EA deliverables has been prioritized and scheduled for development EA refreshes feed into the budget planning cycle An EA governance framework has been created	EA development cycles are planned as projects and tracked for quality, schedule and cost. The EA is refreshed at least annually	The EA development process is reviewed and improved periodically as required. The EA may be updated more frequently when out-of-cycle changes occur
Process Integration	EA Team is somewhat isolated or informally integrated	EA is integrated with the IT change management process and with application portfolio management	EA is integrated with IT project/program management and application development methodologies take into consideration EA.	EA is integrated with the technology acquisition process. EA is integrated with business strategic planning and with business change program management	
Deliverables	Creates deliverables related to Technology trends. Has a reactive view to Future State Planning	Creates Technical and Solution architecture principles and standards. Uses Business capability models sometimes and looks a year ahead when planning Future State	Looks at Project portfolio requirements. Creates Information architecture principles and standards. Future State is planned on a 1-3 years horizon	EA Deliverables shape Business strategies. Develops Business architecture principles and standards. Future state planning 3-5 years ahead	Deliverables looks at Business environmental trends. Future state planning 5 years or more ahead
Disclosure and Compliance	Disclosure and Compliance is informal		EA reviews are integrated into the system development lifecycle (SDLC) process. Projects that are not compliant with EA can be stopped through the review process. The enterprise architecture team is aware of all projects that are planned or underway within the organization	An appropriate appeal process has been defined for architecture review board Decision. EA program compliance is well-defined and clearly communicated within the enterprise. A process is in place to select projects for a formal architecture review based on size, risk and/or other key factors	
Metrics	No Metrics Defined		EA metrics have been identified to track planned to actual EA deliverables. Metrics on Project compliance and the number of projects requiring EA Consulting is tracked	EA metrics have been identified to track the impact of EA on IT and the business. Roadmap adoption is tracked	
Stakeholders Perceptions	EA has a positive impact on reducing IT service provision costs	EA enables reuse of assets	EA has a positive impact on reducing project work effort and on business strategy	EA has a positive impact on optimizing business processes and on improving information quality and accessibility. EA enables innovation	EA has a positive impact on enabling organizational change

Figure 3.11: ITScore for EA (Sullivan, 2011)

Besides their ITScore framework, Gartner also created toolkits from their business capability modeling activities. Business capability modeling visually represents and allows modeling of an organizations business capabilities independent of the organization's structure, processes, people or domains. Gartner's business capability modeling starter kit contains 'anchor diagrams' for ten industries based on input from 27 symposium attendees. These can provide a jump-start in identifying capabilities needed for EA transitions and are based on best practices from the industry.

GAO EAMMF

The Enterprise Architecture Management Maturity Framework (EAMMF) is another maturity framework that has its origins in the U.S. government. The General Accounting Office (GAO) designed a comprehensive model that is geared towards EA management with the goal of maximizing business performance and profit. Version 2.1 of EAMMF uses seven maturity stages across four critical management attributes that total 59 core elements (Government Accountability Office, 2010). The seven maturity levels are:

- stage 0: creating EA awareness
- stage 1: establishing EA institutional commitment and direction
- stage 2: creating the management foundation for EA development and use
- stage 3: developing initial EA versions
- stage 4: completing and using an initial EA version for targeted results
- stage 5: expanding and evolving the EA and its use for institutional transformation
- stage 6: continuously improving the EA and its use to achieve corporate optimization

For these four management characteristics that are recognized as critical to successfully perform any management function, initiative or program.

- attribute 1: demonstrates commitment: activities and efforts that show organization wide commitment to perform EA functions, initiatives or programs
- attribute 2: provides capability to meet commitment: efforts and activities to put capability in place such that the initiative, function or program can be executed
- attribute 3: demonstrates satisfaction of commitment: results that demonstrates and proves an EA function, initiative or program is being performed
- attribute 4: verifies satisfaction of commitment: results that demonstrates and proves an EA function, initiative or program is successfully performed

3.6 Environmental Factors

Various business tools exist that help analyze the environment of an enterprise, two commonly used methods are described below.

3.6.1 PESTLE analysis

The following external sources are used in PESTLE analysis (Allen, 2001; Aguilar, 1967):

Political Uncertainties Government regulations and legal factors can cause uncertainty in the business environment and market. This includes factors such as political stability, tax guidelines, trade regulations, safety regulations and employment laws.

Economic Uncertainties Economic growth, exchange rates, economic cycles, stock market stability, interest rate, unemployment rate, and inflation are examples of economic factors that can cause uncertainty and affect a company.

Social Uncertainties A business can analyze the socio-cultural environment of its market through aspects like customer demographics, public health, cultural limitations, lifestyle attitude, and education. Uncertainties in these can cause misjudgment of client needs and leave an enterprise with undesired/unwanted products or services.

Technological Uncertainties New and emerging or deprecated technologies can disrupt the environment of an enterprise and cause uncertainty.

Legal Uncertainties Law and legislation such as new regulation (e.g. privacy laws) can cause uncertainty.

Environmental Uncertainties Ecological and environmental aspects such as climate change, pollution laws, waste management, eco or fair-trade practices etc. affect business.

3.6.2 SWOT analysis

A SWOT analysis is carried out to identify the degree of strategic fit between the internal environment and the external environment. It can be used to analyze the strengths and weaknesses (typically the internal environment), and opportunities and threats (generally the external environment) of an organization, EA asset or project. A PESTLE analysis therefore can be used in combination with a SWOT analysis, where PESTLE ensures all external factors are taken into account as opportunities and/or threats.

3.7 Risk

As mentioned in section 3.4 we have defined risks as the unknown future events that have a known probability distribution. ISO 31000:2009 on risk management (International Organization for Standardization, 2009a) defines risk as the "effect of uncertainty on objectives". These are a departure from a narrow definition of risk and deliberately includes positive possibilities.

3.7.1 Enterprise Risk Management

Enterprise Risk Management (ERM) are the methods and processes used, ideally established through an ERM framework, in an enterprise to identify and manage risks. Figure 3.12 shows the risk management process according to the International Organization for Standardization (2009a).

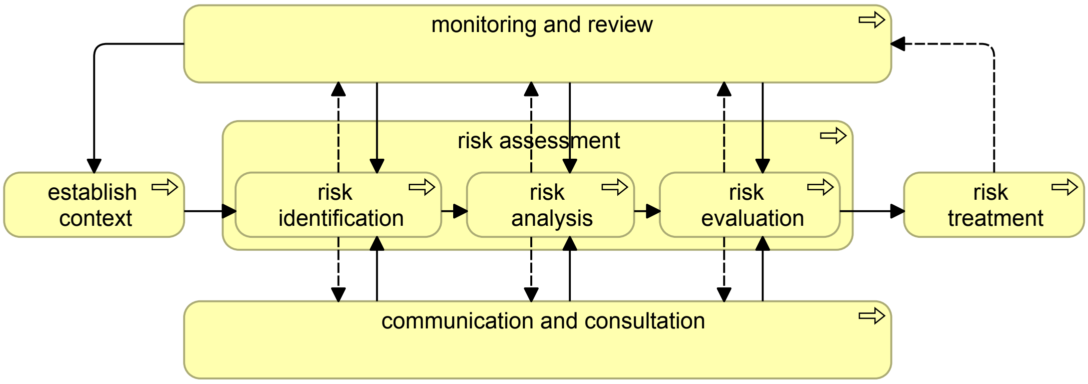


Figure 3.12: Enterprise Risk Management Process

Establish context Establishing the context defines the alignment of the ERM to the internal context, an organizations culture, processes, structure and strategy and its external environment in which the organization seeks to achieve its goals. The external context aligns with the exogenous uncertainty sources in the uncertainty analysis described in section 4.4.2.

Risk assessment Risk assessment is the iterative process of risk identification, analysis, and evaluation. Prior to identification is to establish some form of risk measurement. Typically organizations define scales for risks in terms of impact and likelihood. Curtis and Carey advocates the additional use of velocity, to track how fast a risk can manifest, and vulnerability, to gauge needs for risk mitigation (Curtis & Carey, 2012).

Risk identification Having establishing the areas of uncertainty prior, gives organizations a handle to derive risks. A useful method for risk identification is the use of scenarios, see section 3.7.2 in combination with other identification tools such as interviews, surveys, or benchmarking. ISO/IEC 31010, a supporting standard to ISO 31000:2009, gives an overview and description of risk assessment and identification techniques (International Organization for Standardization, 2009b) that can broadly be categorized in two approaches:

- deductive approaches. A top-down approach that starts with a hypothesis and examines possibilities to reach a logical conclusion i.e. it assumes the ultimate occurrence and deduces its causes.
- inductive approaches: A bottoms-up approach that makes a generalization from specific observations i.e. experts identify a likely risk based on a combination of specific factors.

Risk analysis Risk analysis measures risk and tries to comprehend its nature. It involves consideration of the origins of risk, their positive and negative consequences and the likelihood it can occur.

Risk evaluation By using the measurements from the risk analysis as an input a comparison of risks can be performed that gives a prioritization and select the risks requiring further action.

Risk treatment Risk treatment performs one or more techniques to modify selected risks. The following broad treatment categories are defined in literature:

- avoidance: eliminate the risk by withdrawing from a 'riskful' activity. This may of course not be always possible and can introduce new or impact other risks.
- reduction: reduce the impact severity or occurrence likelihood of a loss. Common reduction strategies include:
  - diversification: diversification reduces risk by spreading risk across assets and/or activities. A diversified portfolio balances risk among activities or assets such that a risk manifestation in one asset/action is mitigated by other actions or assets. Modularization of EA projects or assets allows for finer grained control when balancing risks into diversified portfolios. Therefore, a riskier investment, such as those typically needed in long-term strategic development, that also have great potential, can be counterbalanced by investments with a more guaranteed return on investment.
  - hedging: by investing in options that offset potential losses/gains on activities/assets that have risk. Effective options hedge specific risks, the more granular the risk, again through modularization, the more effective options can be designed specific for the risk which in turn reduces option investment costs.
- sharing: distribute the potential for loss or gain with another party. This is commonly done by sub-contracting, outsourcing and through insurance.
- retention: the acceptance of a potential for loss.

3.7.2 Scenario Planning

To make sense of uncertainties and their relation to other uncertainties and risks, scenarios can be constructed that form 'what if' cases. Scenario planning has a long history from it's formal application within the military during World War II. The success of scenario planning led to its rapid adoption by the business sector through the 1960s-1970s, in particular in its successful use by Royal Dutch Shell during the oil crisis (Schwartz, 1991). Scenario planning has evolved from a 1960s emphasis on predictions based on stable trends, to a shift of coping with irreducible uncertainty in the 1980s and currently put a focus on broad participation of stakeholders and shared decision-making (Rowland, Cross, & Hartmann, 2014). Scenarios provide a powerful way to communicate a story, one that is natural and gives meaning to events. It stimulates decision makers to think outside the box.

3.8 Real Options

Myers (1977) first introduced Real Options (ROs) as opportunities [for a firm] to purchase real assets on possibly favorable terms in the context of strategic decision making (Myers, 1977). 'Real' refers to a non-financial asset and a Real Option (RO) is said to "give the right, but not the obligation to take an action at a future time" i.e. you invest/decide up-front in/on having the flexibility to execute an option (an action), but you are not required to execute it. Myers introduced the term to fill a gap in finance theory to support value calculations of strategic investments through flexibility. It supports value calculation methods developed for financial options on real-assets. Traditional approaches to evaluate investments such as NPV and DCF, Net Present Value and Discounted Cash Flow respectively, do not account for future flexibility and therefore have little support for strategic decision making in environments that deal with high levels of uncertainty. This chapter will introduce options and valuation methods.

3.8.1 Financial Options

In finance a stock or equity option is defined as "a contract that gives its buyer the right to buy or sell a specific stock at a preset price during a certain time period" (Damodaran, 2002). The contract defines the terms; the buyer furthermore pays the seller a premium for receiving these rights that have to be paid regardless if it is exercised or not. Two main types of options exist:

1. Call Option: the right to buy a stock for a predetermined price within the expiration time. With a call Option the buyer expects the stock value to increase and therefore buys the call contract, with call options, from a call Writer (seller of the option) to buy the stock at a predetermined price against a premium.

2. Put Option: the right to sell stock for a predetermined price within the expiration time. With Put Options the put buyer expects a decrease in stock value and therefore buys a put contract, with put options, from a put writer (seller of the option) to sell the stock at a predetermined price against a premium. Put options are often used as an insurance, a protective put, against drastic downward movement of shares hold and a common with other derivatives as part of a hedging technique to offset potential loss.

Different option styles exist categorized by exercise rights:

- American-style option: An option that can be exercised at any time. All equity options are American-style options regardless of geographic location of the exchange..

- European-style option: An option that is only exercisable at expiration time. Various index options are European-style options.

- Bermudan-style option: An option that can be exercised at predetermined dates (typically every month).

Because of these extra rights, American-style option are considered the most valuable and therefore are the most expensive. Bermuda options provide writers with more control yet are not as expensive as American-style options, while also being less restrictive as the cheaper European-style options. Damodaran (2002), Copeland and Antikarov (2003) list the following main determinants of option value:

- Current underlying asset value (S): Today's value of an option, also named spot price. For financial options today's value can be derived from the financial markets. The asset value for real-options however is more complicated as market value might not be available and could be derived from either a twin-security (portfolio with correlating cash flows) or through Market Asset Disclaimer (MAD) as suggested in Copeland and Antikarov (2003) and explained in more detail in section 3.10.

- Volatility (σ) in value of the underlying asset: a higher volatility in value (and greater risk) results in a higher value of the option.

- Dividend (δ) paid on underlying asset: The return paid to shareholders. The value of an asset decreases if dividend payments are made on the asset during the life of the option. In real-options literature a dividend is a cash outflow from the real asset that decreases its value.
- Strike price (K) of option: the amount of money needed to execute the real-option. Call options see a decline of value as the strike price increases, put options an increase. The strike price's relation to the underlying asset value S results in the following strike price categories:
  - 'in-the-money' when $K > S$
  - 'at-the-money' when $K = S$
  - 'out-of-the-money' when $K < S$
- Option expiration time (T): an increase in the time to expiration increases the option value as it provides more time for the value of the underlying asset to move.
- Risk free interest rate (r): the theoretical rate of return of an investment with zero risk often equal to those of treasury bills and bonds.

3.8.2 Real Option Pricing Model

Many pricing models exist that valuate options, in this chapter the most common valuation methods for ROs are discussed and compared. Table 3.6 gives an overview of the models (Kodukula & Papudesu, 2006; Slot, 2010). The higher the uncertainty on the asset the higher the potential option value.

Table 3.6: Option Pricing Models

Option Valuation Technique	Calculation method
Partial differential equations	▪ Closed form solutions (e.g. Black and Scholes) ▪ Analytical approximations ▪ Numerical methods
Simulations	▪ Monte Carlo
Lattices	▪ Binomial (Cox-Rubenstein) ▪ Trinomial ▪ Quadrinomial ▪ Multinomial

Partial differential equations

Partial differential equations have more than one independent variable and have set boundary conditions (e.g. option type, option values at known points and extremes) that describe the change in value with respect to changes in the market. The Black-Scholes Model (BSM) is the most famous closed form solution and gives the option value using one (finite) function.

Black-Scholes Model Scholes and Merton, who contributed an integral part, received a Nobel prize in economics in 1997, Black had died 2 years earlier, for their partial differential equation, named after the authors of the original publication on the calculation of option premiums. The Black-Scholes equation can be used as a model to calculate European put and call options and makes the following assumptions:

- The options are European
- No dividends are paid during the life of the option
- Efficient markets
- No commissions
- The risk-free rate and volatility of the underlying asset are known and constant based on a lognormal distribution of security prices

While many extensions on the equation exist that relax one or more of these assumptions, the basic premise is that the stochastic process that drives the stock values follow a Geometric Brownian Motion (GBM). GBM, also known as Wiener process, satisfies the properties of a Markov process where all information of a stocks past is considered to be represented in its present value. Therefore, the only variable that affects future value is the current present value. The GBM also assumes that price movements in different periods are independent of others and changes in price are normally distributed with a zero mean and standard deviation $\sqrt{\Delta\ t}$ with time step $\Delta\ t$ (Crundwell, 2008). This leads to the Black-Scholes equation to value options shown in equation (3.8) assuming that the dividend yield (δ) equals zero (McDonald, 2013).

$$
\begin{aligned}
Vc &= N(d_1)S - N(d_2)Ke^{-r(T-t)} \\
Vp &= Ke^{-r(T-t)}N(-d_2)S - SN(-d_1) \\
&\text{and} \\
d_1 &= \frac{\ln(\frac{S}{K}) + (r + \frac{\sigma^2}{2})(T-t)}{\sigma\sqrt{T-t}} \\
d_2 &= \frac{\ln(\frac{S}{K}) + (r - \frac{\sigma^2}{2})(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t} \\
\text{where } Vc &= \text{value of the call option} \\
Vp &= \text{value of the put option} \\
N &= \text{standard normal distribution} \\
S &= \text{spot price or current underlying asset value} \\
K &= \text{strike price or cost of investment} \\
r &= \text{risk free rate} \\
T - t &= \text{time to maturity}
\end{aligned}
\tag{3.8}
$$

The inputs K and T define the characteristics of the option contract while the other inputs S, σ describe the stock and the discount rate for a risk-free investment r. Volatility is discussed in more detail in section 3.10. The free interest rate and the volatility are expressed on annual basis and therefore are all multiplied. The equations are easily illustrated with the following example.

BSM calculation example A European call option with a strike price of $\$100$ on a share with the current price of $\$110$ has a volatility of 30% and risk free interest rate of 13%. The option matures in 1 year. Using equation (3.8) we find that:

first d_1 and d_2 can be calculated:

$$d_1 = \frac{\ln(\frac{110}{100}) + (0.13 + \frac{0.3^2}{2})(1)}{0.3\sqrt{1}} = 0.901034$$
$$d_2 = d_1 - 0.3\sqrt{1} = 0.601034$$

then the normal distribution with a mean of zero is calculated:

$$N(d_1) = 0.816215$$
$$N(d_2) = 0.726091$$

now the call option value can be calculated:

$$Vc = 0.816215(110) - 0.726091(100e^{-0.13(1)}) = 26.025889$$

hence the call option is worth $\$26.03$

Since the publication of BSM that solves the option pricing for European options much discussion has persisted on American option pricing. The American option pricing problem is key in capital budgeting when evaluating investments because many projects have future flexibility, to be exercised before its maturity, that can significantly increase value. Discussion also surrounds the assumption that underlying asset returns follow a normal distribution. This is similar to the assumption that the underlying asset prices themselves are lognormally distributed which in practice is not always entirely the case (Bhat, 2009).

Analytical approximations

When completely closed solutions such as the BSM are impossible, approximations can derive an analytical solution. Analytical approximations exist that extend the BSM to American Option pricing. These methods typically are mathematically complex and applied only to simple option structures and therefore seem less suited for Real Option Valuation (Vollert, 2003).

Numerical methods

Numerical methods can be used to solve the partial differential equation when analytical approximation cannot be used. The main representatives with regard to approximating the solution of a system of PDEs are the finite difference methods.

Finite difference methods The finite difference method analyses the partial differential and "uses discrete estimates of the changes in the options value for small changes in time or the underlying stock price to form difference equations as approximations to the continuous partial derivatives" (Geske & Shastri, 1985).

Simulations

Monte Carlo Monte Carlo simulations, named after the famous casino in Monaco, are computational algorithms that rely on repeated random sampling to solve problems of a stochastic or deterministic type. It has found various and widespread use as the computationally intensive calculations can now be performed by almost all computer systems and even in common spreadsheet software. Monte Carlo calculations typically follow the following generic steps:

1. define the scope of possible inputs
2. generate random inputs according to a probability distribution (e.g. brownian, normal or lognormal distributed)
3. perform calculation
4. aggregate outputs

Monte Carlo simulations have been popular for (real) option valuations as they can be used to calculate the value with multiple sources of uncertainty and unlike the Black-Scholes equation Monte-Carlo based approaches exist to value American style options. The basic Monte Carlo method to value a security consists of the following steps:

1. simulate sample paths of the underlying variables (e.g. underlying prices and interest rates) over the relevant time scope. Simulate these according to the risk-neutral measure.
2. Evaluate the DCF of a security on each sample path
3. Average the DCF over sample paths.

Lattice Models

In 1979 Cox et al. presented a simplified option pricing approach based on a probability tree with chance branches that represent the possible different paths that an asset price might follow over the duration of its life (Hull, 2009). A lattice is a special type of tree that recombines branches, meaning that an up-movement followed by a down-movement results in the same node as a down-movement followed by an up-movement. Lattice models are characterized by the number of branches that originate from each node, the lattice model Cox et al. proposed allows only one up and one down branch in each lattice node and therefore represents a binomial-lattice hence the method is known as the Binomial Option Pricing Model (BOPM). Although other lattice models such as a trinomial model, where the underlying asset can follow three possible values, a quadrinomial model, with four possible values, or multinomial models, with an arbitrary number of possible values, exist their use for ROs has been limited due to their complexity and most ROV literature uses BOPM (Kodukula & Papudesu, 2006; Aarle, 2013). Binomial trees, and therefore lattices, describe the underlying instrument value over a period of time rather than a single point. Therefore, unlike the Black-Scholes equation, it can be used to value both American options and Bermudan options and are seen to handle a variety of conditions that other models cannot easily cope with. The BOPM model is build on similar assumptions, besides this execution time, as the Black-Scholes equation. Figure 3.13 shows a binomial lattice for an asset with the initial value S. The price of the asset can either move up to the value of S_u with a probability p or down to S_d with a probability of $1-p$. The stock value in BOPM is said to follow a random walk, or more accurately a random walk provides the foundation for modeling stock prices and assets in these binomial lattices.

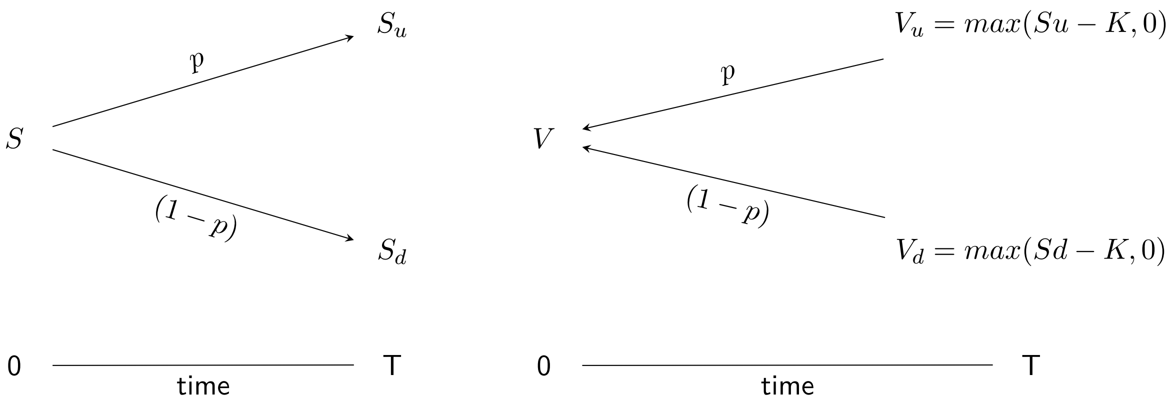
Factors u (for up) and d (for down) can be determined using various methods. As mentioned above the most common method, and the one originally proposed with BOPM, is the Cox-Ross-Rubinstein (CRR) model. In CRR u and d are derived when volatility σ is known and an underlying normal distributed model is assumed using equations (3.9) and (3.10).

$$u = e^{\sigma\sqrt{\Delta t}} \tag{3.9}$$

$$d = 1/u \tag{3.10}$$

With u and d calculated a full binomial lattice, as shown in section 3.8.2, can be drawn for n steps. A decision lattice that injects the option value can be derived from this binomial lattice

Figure 3.13: Binomial lattices for one period



(a) Share price evolution lattice

(b) Call option price evolution lattice

by backtracking through the binomial lattice, based on figure 3.13. Backtracking starts in the terminal nodes by comparing the projected value to the executed option value and selecting the maximum value using equation (3.11).

$$\begin{aligned} V_{node} &= max(terminalvalue, optionexercisevalue) \\ \text{where } V_{node} &= \text{value selected in terminal node} \\ terminalvalue &= \text{value of terminal node} \\ optionexercisevalue &= \text{value of exercising the option} \end{aligned} \tag{3.11}$$

From the terminal nodes the nodes leading up to the terminal nodes are determined by using equation (3.12) to calculate the probability p and $(1-p)$ of respectively an up- and down-move.

$$\begin{aligned} p &= \frac{e^{(r-q)\Delta t} - d}{u - d} \\ \text{where } p &= \text{probability of up move} \\ r &= \text{risk free rate} \\ q &= \text{divident yield} \\ \Delta t &= \text{time period} \\ u &= \text{up movement factor} \\ d &= \text{down movement factor} \end{aligned} \tag{3.12}$$

With p calculated the value of earlier nodes is then determined by comparing the binomial value as calculated by equation (3.13) with the value of exercising the option as shown in equation (3.14).

$$\begin{aligned} binomial\ value &= [p * optionup + (1-p) * optiondown]e^{(-r\Delta t)} \\ \text{where } binomialvalue &= \text{fair price of derivative when not executing the option} \\ p &= \text{probability of up move} \\ 1 - p &= \text{probability of down move} \\ optionup &= \text{value of later ``up'' node} \\ optiondown &= \text{value of later ``down'' node} \\ r &= \text{risk free rate} \\ \Delta t &= \text{time period} \end{aligned} \tag{3.13}$$

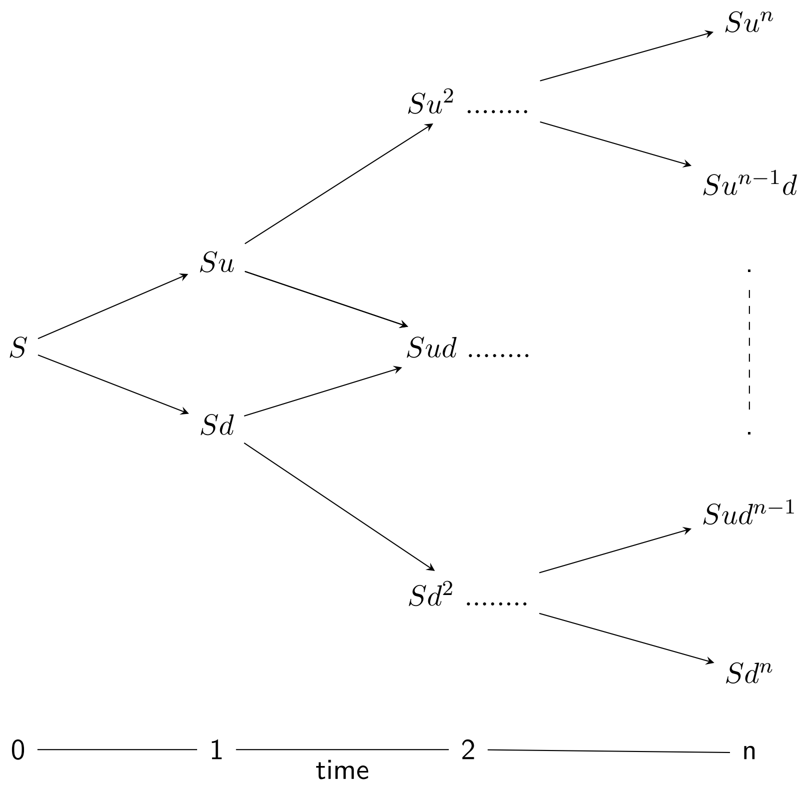


Figure 3.14: Binomial lattice for n period

$$
\begin{aligned}
node\ value &= \max(binomial\ value, option(s)\ exercise\ value)\\
\text{where } node\ value &= \text{value selected in node}\\
binomial\ value &= \text{fair price of derivative when not executing the option}\\
option(s)\ exercise\ value &= \text{value if option(s) is/are exercised}
\end{aligned}
\tag{3.14}
$$

Other binomial models exist, such as the TIAN and Leisen Reimer models, that extend or change the CRR model by modifying and extending on the formulas to calculate the up, down movements and its probability (Chung & Shih, 2007). Since these are direct derivatives from CRR, they typically can be used in the same manner with minor modifications but were not investigated in the context of this research.

Binomial Option Pricing Model example To construct a binomial lattice a spot price S in this example is set to $\$120,000.00$. The forecasted period considered is 7 years and a volatility of 40% is used as estimated by for example a market proxy approach, through the MAD assumption using a logarithmic present value approach, or simulation as explained in more detail in section 3.10. First the up and down factors u and d as shown in equation (3.9) and equation (3.10) needs to be determined:

$$u = e^{0.4\sqrt{1}} = 1.4918$$

$$d = e^{-0.4\sqrt{1}} = \frac{1}{u} = 0.6703$$

with u and d the probability p can be calculated using equation (3.12):

$$p = \frac{e^{0.13} - d}{u - d} = 0.5703051545$$

Using u and d a binomial lattice can be build for 7 time periods shown in table 3.7. By using

Table 3.7: Binomial lattice example

0	1	2	3	4	5	6	7
120 000.00	179 018.96	267 064.91	398 414.03	594 363.89	886 686.73	1 322 781.17	1 973 357.61
	80 438.41	120 000.00	179 018.96	267 064.91	398 414.03	594 363.89	886 686.73
		53 919.48	80 438.41	120 000.00	179 018.96	267 064.91	398 414.03
			36 143.31	53 919.48	80 438.41	120 000.00	179 018.96
				24 227.58	36 143.31	53 919.48	80 438.41
					16 240.23	24 227.58	36 143.31
						10 886.15	16 240.23
							7297.21

backward induction on the binomial lattice in table 3.7 we can add the value of flexibility. Suppose the firm in the example has the ability to scale-down the project at any time by 50 percent, generating additional savings of $\$75,000$ if exercised. The cost up-front of this option is an additional $\$15,000$. By constructing the decision lattice shown in table 3.8 a value of $\$137,045.94$ is obtained which can be compared to the original $\$120,000.00$ plus the additional premium, therefore valuing this abandonment flexibility at $\$137,045.94-\$120,000-\$15,000 = \$2,045.94$. Based on these estimations investing in this abandonment option makes financial sense. Appendix G shows how this example can be easily calculated by running a Matlab script.

Table 3.8: Decision lattice example

0	1	2	3	4	5	6	7
137 045.94	186 852.09	270 143.71	399 219.77	594 363.89	886 686.73	1 322 781.17	1 973 357.61
	115 219.20	136 673.99	186 109.36	269 200.39	398 414.03	594 363.89	886 686.73
		101 959.74	115 219.20	135 957.53	184 678.66	267 064.91	398 414.03
			93 071.65	101 959.74	115 219.20	135 000.00	179 018.96
				87 113.79	93 071.65	101 959.74	115 219.20
					83 120.12	87 113.79	93 071.65
						80 443.08	83 120.12
							78 648.60

3.8.3 Real Option Types

Mikaelian (Mikaelian, 2009) views ROs as a right (but not obligation) to take an action constituted by a mechanism that enables flexibility. The mechanism typically involves an investment whereas the possible flexibilities can be broadly categorized as (Ullrich, 2013; Harvey, 1999; Fichman et al., 2005):

- Relating to Time
  - Deferral option: flexibility to choose when to start (and delay) a decision. This allows for example to wait until market conditions become favorable. Deferral

enables the wait-and-see strategy often employed by large companies in unexplored markets. A defer option behaves analogue to an American call option on a stock.

- Abandon option: flexibility to cease an operation during its lifetime. If an investment evolves unfavorable, abandonment can prevent substantial loss or return a salvage value. Abandon options behave as American put options.
- Temporary-stop option: flexibility to temporarily stop an option (if the cost-revenue ratio becomes unfavorable)
- intra-inter project/sequencing option: Dependency of options through compound options.

- Relating to Size
  - Scale-up/expand option: flexibility to expand scale (when conditions are favorable).
  - Scale-down/contract option: flexibility to forgo on a set of future expenditures. Requires a level of project modularization.
  - Switching option: flexibility to both expand and contract.
- Relating to Operation
  - Output mix: flexibility to use an option for different outputs
  - Input mix: flexibility to use different inputs in option to get the same output
  - Operating scale: flexibility to change output rate per unit of time or total production run time

3.9 Decision Tree Analysis

Decision trees are, like binomial trees and lattices, a visual and analytical tool to model decisions and possible consequences. Decision trees provide the enterprise a graphical way of displaying a decision road map of strategic initiatives and risk (including opportunities) over time. Decision Tree Analysis considers these risks and models the initiative, in the decision tree, in stages in order to devise possible treatments to outcomes at each stage. Decision trees are build using nodes and branches that grow from left to right and, unlike binomial trees, include the following node types:

1. decision nodes: representing a choice from which two or more competing options are available (represented by squares).
2. chance nodes: representing the possible outcomes with respective probability (represented by circles)
3. end nodes: representing a fixed value (represented by triangles)

The first decision node, on the left, represents the root node which starts the decision tree. The analysis tries to determine its optimal value by calculating an optimal path backward from its branches as shown below. Research indicates 32.8% of 175 interviewed companies use decision tree analysis to support strategic decision making (Roelfsema, 2014).

3.9.1 Decision Tree Example

Figure 3.15 shows a simple example decision tree with only one choice and one chance node. It represents an opportunity on either a risky or a safe investment. The safe option, that passes on the investment opportunity, shown in the bottom branch, guarantees $\$15$. If more risk is taken, by investing as shown in the top branch, there are two possible outcomes. There is a chance

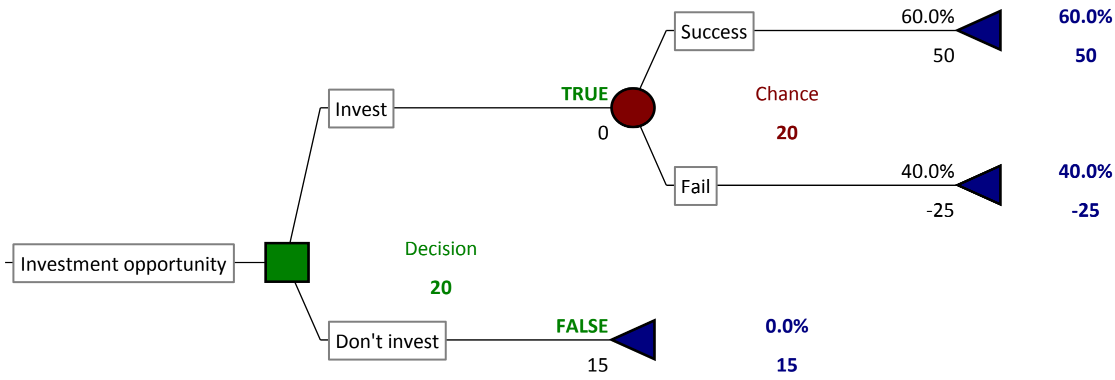


Figure 3.15: Decision Tree example

of success of 60% that wins $\$50$ or a chance of failure that loses $\$25$. Solving the decision tree involves calculating the expected value of the chance node, $60\% * \$50 + 40\% * \$ - 25 = 20$, and compares it with the $\$15$ value of the other option. In this case, on pure expected values, the riskier option would represent better value.

3.9.2 Decision Tree Analysis Development

Damodaran (2008) gives an overview of the common steps involved in developing a decision tree for analysis.

1. Phase analysis by risk.
2. Estimate probabilities of each outcome.
3. Define decision points.
4. Estimate values at end nodes.
5. Fold back the tree.

Dividing the analysis into risk phases requires identifying possible events that might occur in the future, the relationship with other phases (e.g. sequential, concurrent, etc.) and defining their outcomes. For each phase calculate the probabilities of each outcome, ensure they sum up to one and identify dependencies with probabilities of earlier phases. Decision points determine the moments in time where, based on results obtained in passed phases, a choice can be made to select the best course of action. With the structure of the decision tree complete the final cash flows can be computed at each end node. Folding back the tree involves backtracking through the tree computing expected values at each node as demonstrated in the example above. Chance nodes are computed by calculating the weighted average of all possible outcomes and for a decision node the highest value, representing the optimal decision, is selected. The outcome of an analysis is the expected risk adjusted present value that incorporates risks with their possible treatments and a range of values at each end node adjusted for potential risk.

3.10 Volatility

Volatility gives an indication of the variability, measured as a standard deviation, of the total value of the underlying asset over its lifetime and signifies the uncertainty associated with the cash flows that comprise the underlying asset value (Kodukula & Papudesu, 2006). Determination of volatility for financial options is relatively straightforward as it can be derived from market or historical data. For non-market traded assets such as those underlying ROs this data often does not exist and it can even be unclear as to what the underlying asset exactly should be (Luiz E. Brandão et al., 2012). Further due to its significance in ROV methods, volatility estimation is seen as one of the greatest challenges practitioners face in using ROs. To get by the lack of historic or market data Copeland and Antikarov present an approach that considers the value of the project without real options as the best unbiased estimator for the market value of an option, which they termed the Marketed Asset Disclaimer (MAD) assumption. Under this assumption a project without options serves as the underlying asset in the option valuation model and changes to the value of the project without options are assumed to vary over time according to a Geometric Brownian Motion (GBM) stochastic process. GBM is commonly used for asset value models and traditional option pricing methods, such as the binomial lattice method, can then be used to value the project options. Mun describes the following volatility estimation approaches under the MAD assumption.

3.10.1 Logarithmic Cash Flow Returns

The volatility is estimated by using the individual future cash flow estimates and their corresponding logarithmic returns. It involves the following steps:

1. Forecast project cash flows.
2. Calculate relative returns for each period starting with the second period and dividing the current cash flow value with the previous one.
3. Take the natural logarithms of each relative return.
4. Calculate the standard deviation of the natural logarithms.

An example is given in table 3.9. An advantage of this method is that it's easy to implement, widely used on financial assets and does not require Monte Carlo simulation. A big downside to the method is that it does not work if the relative returns are of a negative value as no logarithm of a negative value exists. It therefore does not fully capture downsides in cash flows. Another problem is that autocorrelations between cash flows or cash flows with a static growth rate will erroneous volatility estimates (Mun, 2002).

Table 3.9: Logarithmic Cash Flow Returns example

Time period	Cash Flows ($)	Cash Flow Relative Returns	Natural Logarithm of Cash Flow Returns
0	8	-	-
1	9	$\frac{9}{8} = 1.125$	$\ln(1.125) = 0.1178$
2	9	$\frac{9}{9} = 1$	$\ln(1) = 0$
3	10	$\frac{10}{9} = 1.11$	$\ln(1.11) = 0.1054$
4	15	$\frac{15}{10} = 1.50$	$\ln(1.50) = 0.4055$
	volatility (σ)	stdev(0.1178, 0, 0.1054, 0.4055) $=$ 17.38%	

3.10.2 Logarithmic present value approach

This method, as described in Mun (2002) and introduced by Copeland and Antikarov, collapses all future cash flow estimates into two sets of present values, one for the current time period and one for the first time period (Copeland & Antikarov, 2003).

1. determine constant discount rate
2. forecast and discount cash flows to current and first time period
3. sum values and take logarithmic PV ratio using equation (3.15)
4. perform a Monte Carlo simulation on the DCF simulating only PVCF nominator values
5. volatility is the standard deviation of the forecast distribution of logarithmic PV ratio X

Since the present values shown in equation (3.15) are discounted at the discount rate this methods volatility estimations have a high dependency on the correctness of the used discount rate. It is also computationally more complex as it requires Monte Carlo simulations.

$$\begin{aligned} X &= \ln(\frac{\sum_{i=1}^{n} PVCF_i}{\sum_{i=0}^{n} PVCF_i}) \\ \text{where } X &= \text{logarithmic present value ratio} \\ PVCF_i &= \text{present value of future cash flows at different time periods i} \end{aligned} \tag{3.15}$$

Table 3.10: Logarithmic Present Value Approach example

Discount rate	13%		
Time period	Cash flows ($)	Present Value at time 0 ($)	Present Value at time 1 ($)
0	8	$\frac{8}{(1+0.13)^0} = 8.00$	-
1	9	$\frac{9}{(1+0.13)^1} = 7.96$	$\frac{9}{(1+0.13)^0} = 9.00$
2	9	$\frac{9}{(1+0.13)^2} = 7.05$	$\frac{9}{(1+0.13)^1} = 7.96$
3	10	$\frac{10}{(1+0.13)^3} = 6.93$	$\frac{10}{(1+0.13)^2} = 7.83$
4	15	$\frac{15}{(1+0.13)^4} = 9.20$	$\frac{15}{(1+0.13)^3} = 10.40$
Sum		39.14	35.19
Logarithmic present value ratio		$\ln(\frac{39.14}{35.19}) = -0.10$	

3.10.3 Project and market proxy approach

Kodukula and Papudesu describe the project proxy approach as an indirect approach where historical project data is used of a project similar to the current project. It assumes the historical project has similar cash flows and market performance and leverages real world information to estimate a realistic volatility. The market proxy approach is similar to the project proxy approach except that it uses the market value of a publicly traded company that has a comparable cash flow profile and risk to the current project. Proxy approaches are simple but can only be used if a comparable proxy can be found. Note that publicly traded companies are typically leveraged whereas individual projects are not.

3.10.4 Management assumption approach

A management assumption approach has management estimate an optimistic, pessimistic and average payoff for a project. Assuming that the payoff follows a lognormal distribution there is a 98% probability that the payoff will not exceed the optimistic estimate and a 2% probability it will be below the pessimistic estimate. The average estimation will correspond to the 50% probability and by using any of the two estimates the volatility can be calculated using equations (3.16) to (3.18) (Kodukula & Papudesu, 2006).

$$\begin{aligned} \sigma &= \frac{\ln(\frac{S_{opt}}{S_0})}{2\sqrt{t}} \\ \text{where } \sigma &= \text{volatility} \\ S_{opt} &= \text{optimistic payoff} \\ S_0 &= \text{average payoff} \end{aligned} \tag{3.16}$$

$$\begin{aligned} \sigma &= \frac{\ln(\frac{S_0}{S_{pes}})}{2\sqrt{t}} \\ \text{where } \sigma &= \text{volatility} \\ S_0 &= \text{average payoff} \\ S_{pes} &= \text{pessimistic payoff} \end{aligned} \tag{3.17}$$

$$\begin{aligned} \sigma &= \frac{\ln(\frac{S_{opt}}{S_{pes}})}{4\sqrt{t}} \\ \text{where } \sigma &= \text{volatility} \\ S_{opt} &= \text{Optimistic payoff} \\ S_{pes} &= \text{Pessimistic payoff} \end{aligned} \tag{3.18}$$

Chapter 4

FEUD

This chapter presents the **Framework for Enterprise Uncertainty-driven Decision-making**, 'FEUD' in short. A framework that supports integrated decision making in enterprise architectures. FEUD relies on the theories and research reviewed in chapter 3 and a case study follows that shows its perceived practical use in chapter 5.

4.1 Introducing FEUD

Change is imposed on or pursued by organizations for many reasons and often leads to EA transformations. Because of EA complexity, transitions typically deal with a great deal of uncertainty. During an EA design and implementation many decisions are required on EA assets and in projects. These take place in any of the EA dimensions, explained in section 3.1, and can affect or effect (many) other EA decisions. By incorporating uncertainty identification early in the decision making process resulting risks can not only be managed but the EA can be designed such that the cost of changes to the EA due to manifestations of risks will be minimal. This is characterized in the definition Grady Booch, developer of the Unified Modeling Language (UML), gives of architecture: "architecture represents the significant design decisions that shape a system, where significant is measured by cost of change" (Monson-Haefel, 2009). FEUD therefore incorporates methods that explicitly deal with uncertainty in order to reduce the cost of change and creates a decision-making framework that supports EA holistically.

4.2 Integrated EA decisions

EA as a discipline enables organizations to make better informed choices across their strategy, business and IT. Key to a successful EA is the "strategic alignment" of these decisions, meaning that decisions in one such area are made in orchestration with other decisions in other areas. The EA process itself can be viewed as a series of choices to get from a current state to a possible target state. An EA Decision-Making framework, as proposed in this thesis, is a structure that helps decision makers base, model and document their EA decisions. In an EAF the strategic investment decisions are the investments that occur on the highest and most abstract level of an enterprise that subsequently flow down to decisions on more concrete investments. Figure 4.1 shows a simplistic graphical representation of how investments and how value flows in an enterprise. The triangle represents the context of an enterprise and the strategy, top level, of an enterprise will return value to its context (i.e. investors). Each layer from Zachman's taxonomy, also represented by Archimate, requires decisions on investments that enable options and returns value to previous investment decisions. As such an EA model can be viewed as the result of a chain, or more likely one ore more graphs, of decisions on EA options that relate to other decisions on options. EA options consist of EA assets or transitions and thus are not restricted to a single dimension of EA either. Analogue to Mikaelian (2009)'s characterization of a real option in both a mechanism and type, a decision on an EA option can be described by the investment needed and value expected, as well as the option description (i.e. EA assets and transitional aspects) and considered option alternatives. A real option in this context is an EA option extension that can generate value, in the form of flexibility, at a later time with the goal to increase the options value.

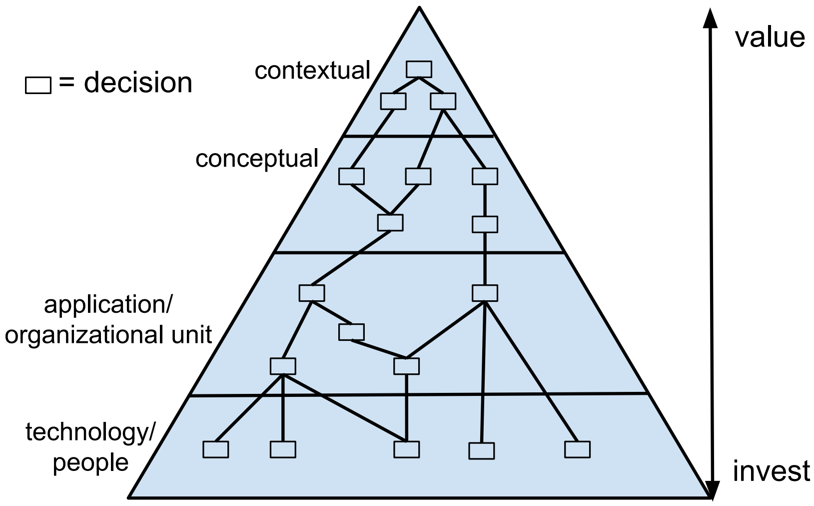


Figure 4.1: Enterprise Investment Decision Graph

4.3 EA decision-making conceptual-model

Based on the work by Plataniotis et al. and the specification in The Open Group (2013) the EA decision support conceptual-model in figure 4.2 for Archimate is created. This model depicts the identified concepts and their relationships and the background to establish a language meta-model with mappings to Archimate concepts.

EA Decision The EA Decision is the decision on the EA asset that represents the result of the decision making process. It can represent any Archimate element or a set of Archimate elements or chain of decisions. In Archimate's motivation dimension EA decisions typically involve choosing between goals with associated motivational concepts that represents a choice

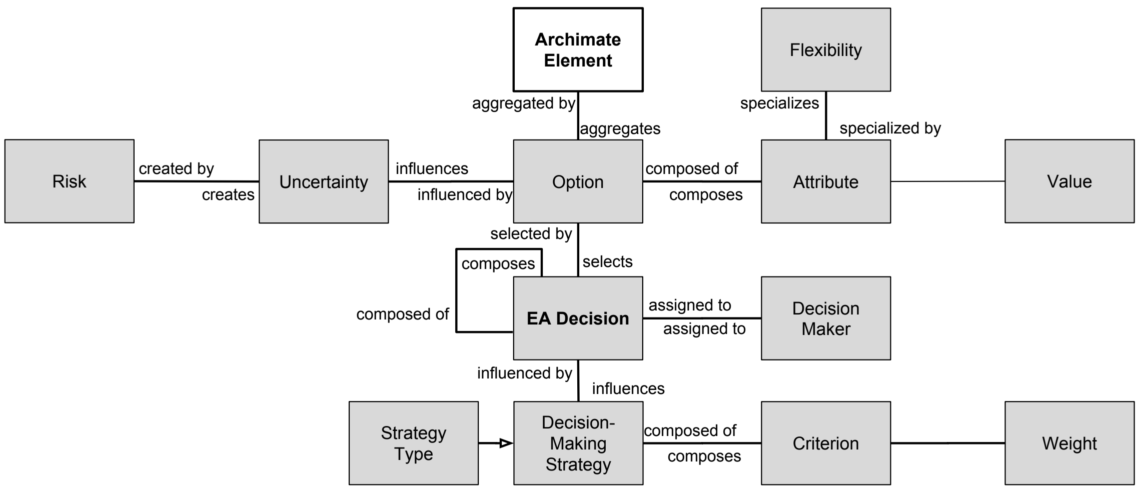


Figure 4.2: FEUD Conceptual Model

of strategy. The Archimate core can be realized by EA choices on EA asset alternatives, choices on Archimate's implementation and Migration elements typically represent EA project choices.

Decision Maker A specialization of the business actor element that is governing the decision. Decision makers have the authority over and bear the accountability for decisions made and its definition is in line with definitions used by literature on IT Governance (Simonsson & Johnson, 2006; Van Grembergen et al., 2004).

Decision Making Strategy and Strategy Type This is the decision making strategy used by the decision maker as discussed in section 3.3 by Plataniotis et al. It is expected that the choice for a strategy greatly depends on the complexity of the choice to be made, the culture in the enterprise, the decision-maker and for more complex choices often uses a combination of strategies.

Criterion and Weight Depending on the strategy chosen different criterion are used that evaluate the alternatives using an associated weight.

Option An option represents the subject of a decision, represents a flexibility of choice, and is composed of EA elements. If multiple options exist they can be defined as "alternatives" and are in line with the definition used by Plataniotis et al. detailed in section 3.3 representing the available choices that are under evaluation using a specific decision making strategy.

Attribute, Flexibility and Value Attributes represent those elements of an option that are important to evaluate and can be measured using a value. Flexibility is a specialized attribute that can be made measurable by using Real Options Valuation and can be an important element for valuation when dealing with uncertainty.

Uncertainty Represents the uncertainty associated with the EA decision alternative. Uncertainty is discussed at length in section 4.4.

Risk Risk is the uncertainty made tangible by identifying/defining its probability distribution. FEUD distills risk from uncertainty (see section 4.5.3, or if a risk is identified first, an uncertainty is sourced from risks.

4.4 EA Uncertainty

A successful enterprise architecture should empower decision makers with flexibility in order to respond to risks with (as) little architectural consequences (as possible) (Monson-Haefel, 2009). The advantage of eliciting uncertainties is that it can take place very early in EA projects and helps structure and support the identification of risks as detailed in section 3.7. Uncertainty in an EA originates from a wide variety of sources and can impact virtually every aspect of an enterprise. It affects both architectural assets (e.g. applications, processes, infrastructure) and changes (e.g. projects, transitions). Because decisions on these assets and changes are made with incomplete knowledge they therefore deal with uncertainty that can lead to risks. Figure 4.3 gives an overview, based on work by Weck et al., of the classification of sources of uncertainty pertaining to EA as used in this model and explained in section 3.4 (Weck et al., 2007).

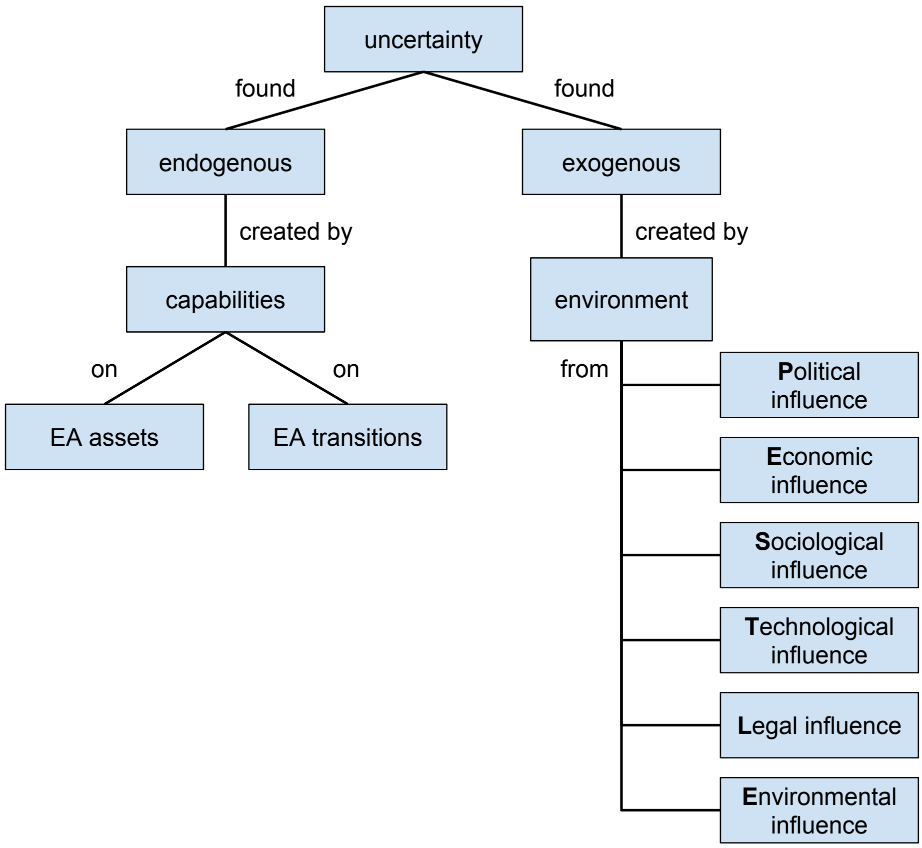


Figure 4.3: Uncertainty sourced overview

4.4.1 Endogenous

Endogenous or internal uncertainty originates from capabilities, see section 3.5, within the EA. The level or maturity of these capabilities determines the amount of uncertainty. Each EA activity requires different capabilities and involves different EA assets with their corresponding capabilities. Capability maturity models can support identification and assessment of required capabilities. For example, an organization that has an assessed lower level of maturity on the vendor-management business-capability can be expected to have an increased uncertainty on projects that involve outsourcing. Furthermore each EA dimension has assets that can be assessed for capabilities important to an EA project. For example, a cloud-based IT infrastructure has different capabilities on for example areas of scalability and security as an in-house IT infrastructure. Whether a capability is significant and if it is a cause for uncertainty for current EA projects will need to be determined.

4.4.2 Exogenous

Exogenous or external uncertainty stems from sources outside the direct control of an enterprise. To help identify external sources of influence analysis frameworks such as SWOT, and PESTLE exist, see section 3.6, that provide a handle for enterprises to support analysis of their context.

4.5 FEUD decision-making process

FEUD presents a generic iterative model that can be integrated with EA development methods from EAFs. This chapter describes a generic decision support process as represented by the Uncertainty Driven EA Decision Making Cycle (UDEADMC) shown in figure 4.4. It explains each phase using a simple decision making example, note that it is expected to be performed iteratively, both as a whole and between phases. The following chapter discusses the model in an EA context.

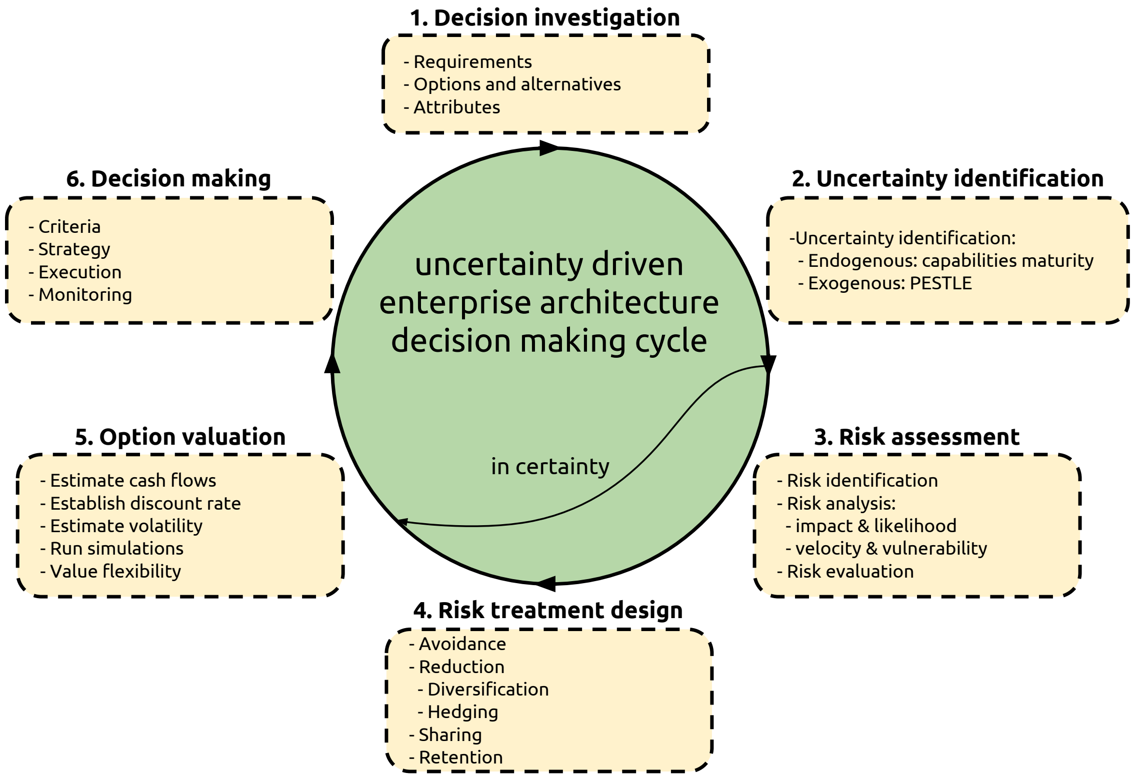


Figure 4.4: Uncertainty Driven EA Decision Making Cycle

4.5.1 Decision investigation

We are daily faced with decisions, it can be argued that our ability to recognize decisions increases and potentially improves our control on future events. Options give the right of choosing and decisions can be made on one option or multiple in which case options become alternatives. Conscious decisions are made with certain objectives in mind. Archimate captures objectives in the motivation extension, described in detail in section 3.1.3. This is best illustrated using a deliberately simplistic decision example on a decision of commute options elaborated on in each coming section.

Decision investigation example: Elizabeth's commute

Getting to work on time and in a representable state is important for Elizabeth's career. Elizabeth is faced with an investment decision on her commute. Two alternative options are identified that allow Elizabeth to arrive on time, before eight in the morning, and be representable (her main requirements). The first option is to drive a car, while the second option is to take a bicycle. By analyzing these options, it was initially determined that the most important attribute is the duration of transportation. Further analysis however revealed

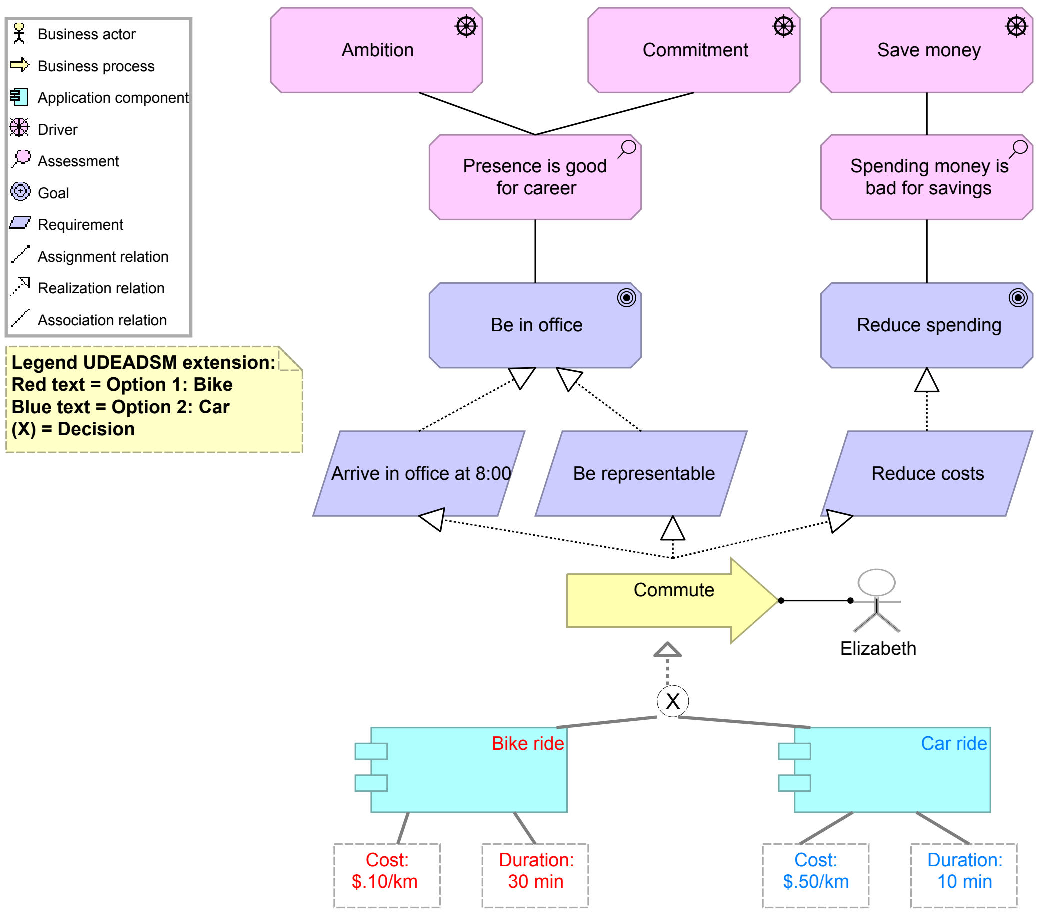


Figure 4.5: Example Archimate Decision Investigation

that she also has a need to consider associated costs. Therefore, additional requirements are added that represent a cost saving objective. Figure 4.5 depicts an Archimate representation of this decision using the standard motivation extension and adds decision and options with attributes (see the yellow note in the figure for a legend of added items).

4.5.2 Uncertainty identification

In reality important decisions deal with (some) uncertainty. Having too much uncertainty can paralyze the decision making process or result in irrational decision-making, denoted by Gneezy, List, and Wu as the "uncertainty effect" (Gneezy et al., 2006), and has also widely been observed in financial markets during a crisis (Krishnamurthy, 2010). The proposed first step to determine uncertainty is by analyzing its possible sources. Sources of uncertainty are categorized by their origin type, endogenous for internal, and exogenous for external sources. As explained in section 3.4 endogenous uncertainty is seen to relate to measures of capabilities relevant to the decision and exogenous uncertainties can be traced to the political, economic, social, technological, legal, and environmental (PESTLE) origins. If no uncertainties have been found or a potentially dangerous decision is made to ignore them, the decision process can continue with option valuation in section 4.5.5.

Uncertainty identification example: Elizabeth's commute

Elizabeth identifies uncertainty by looking at potential sources that affect the commute. All identified uncertainty, in orange, and sources, as capabilities and environmental sources, are added to the Archimate diagram shown in figure 4.6.

Endogenous sources To identify endogenous uncertainty, a capabilities review was performed to find the capabilities relevant to the morning and evening commute. The assessment found only the 'Stamina' capability to be relevant, which was seen to cause uncertainty on the duration of the bicycle commute. Because Elizabeth's current stamina capabilities are considered unproven, as she just started riding bicycles, its maturity was estimated to be low.

Exogenous sources Using a PESTLE analysis, the sources of external uncertainty were investigated for each mode of commute. The bike ride was considered to be influenced by weather uncertainty due to environmental sources, whereas the car ride 'suffered' from uncertainty on the intensity of traffic due to external social sources.

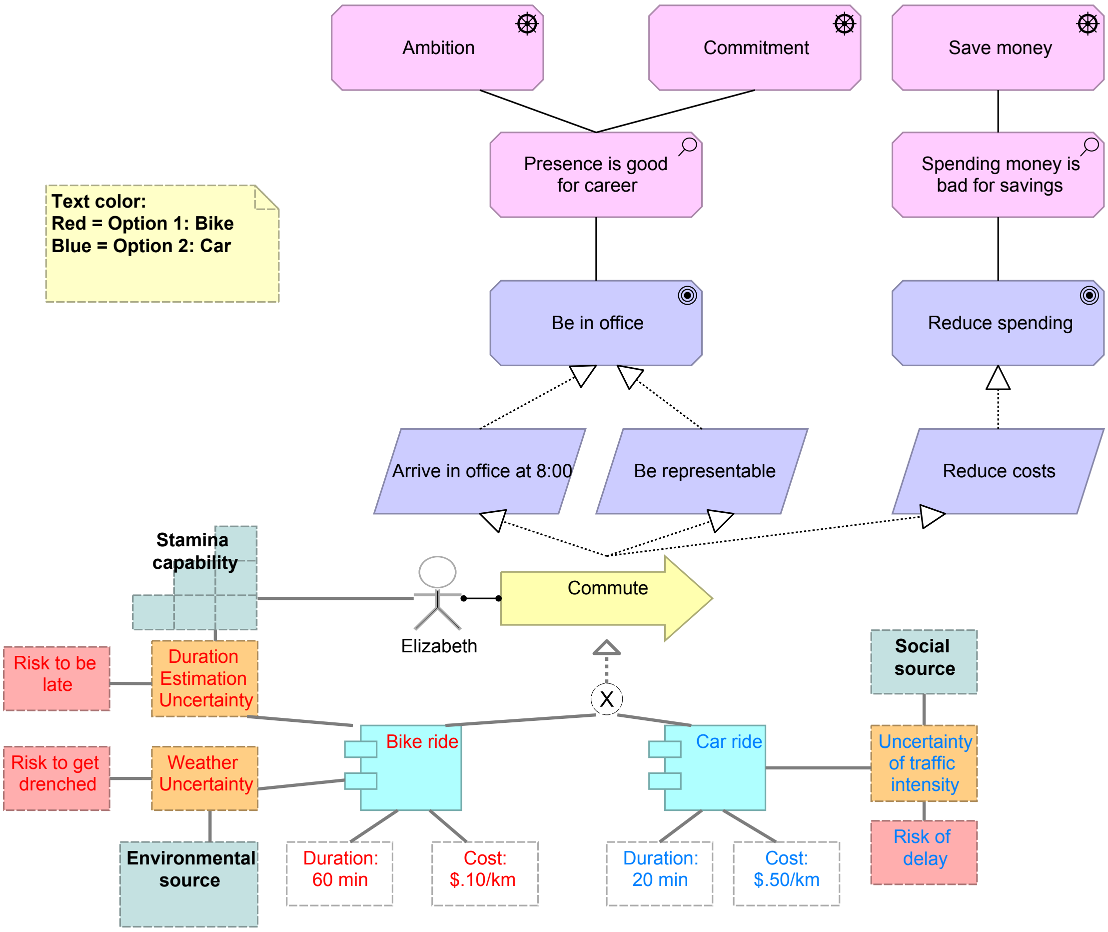


Figure 4.6: Example Archimate Uncertainty identification and Risk assessment

4.5.3 Risk assessment

Recognizing uncertainty allows for a systematic identification of risks. While uncertainty can disrupt decision making, understanding risks can actually support it. Risks can create opportunities to invest in higher yield options and allows risks to be treated and managed. ISO 31000:2009 describes, discussed in section 3.7, a generic risk assessment process for ERM that is integrated in this decision-support model. The risk context is established by investigating the decision and options (section 4.5.1) and by identifying uncertainties (section 4.5.2).

Risk identification

Risk identification, the first step in risk assessment, builds upon the uncertainties identified in the previous step. The uncertainties established by both internal and external analysis in section 4.6.2 provide a logical input to initiate risk identification (Stamatelatos, 2002). If an enterprise has established Enterprise Risk Management (ERM) practices these can be leveraged by the decision support model by aligning its risk identification practices with the identified uncertainties. Alternatively, if risks were identified first it has benefits to determine the originating uncertainties as this can support identification of new (previously missed) risks. ISO/IEC 31010:2009 (International Organization for Standardization, 2009b) categorizes risk assessment strategies in:

- evidence based methods. This includes historic risk analysis within the company but also can include analysis of external entities sharing applicable commonalities (e.g. industry, technological profile, geographic location). Previous uncertainty assessments along with risk manifestations, both endogenous and exogenous, can be analyzed and compared with the current uncertainty assessment.
- systematic team approaches. These include interviews and workshops that rely on experts, ideally in a cross-functional group to encourage thinking outside functional silos, to analyze uncertainties and discover risks.
- inductive reasoning techniques. Analyze events to induct a risk. An expert can identify probable risks based on the occurrences of several events as described in frameworks.

Better results are expected when a combination of strategies are applied that include both inductive and deductive approaches, see section 3.7.1. Documenting these risks with their relationships to uncertainties and its sources effectively creates a 'Risk Repository' that an enterprise can consult in future EA projects to quickly identify and assess risks. The structure, exact content and implementation of such repository is beyond the scope of this research.

Risk analysis

Risk analysis assesses risks on a common set of criteria. This model suggests evaluating risks in 5 levels on the following four dimensions based on Curtis and Carey (2012):

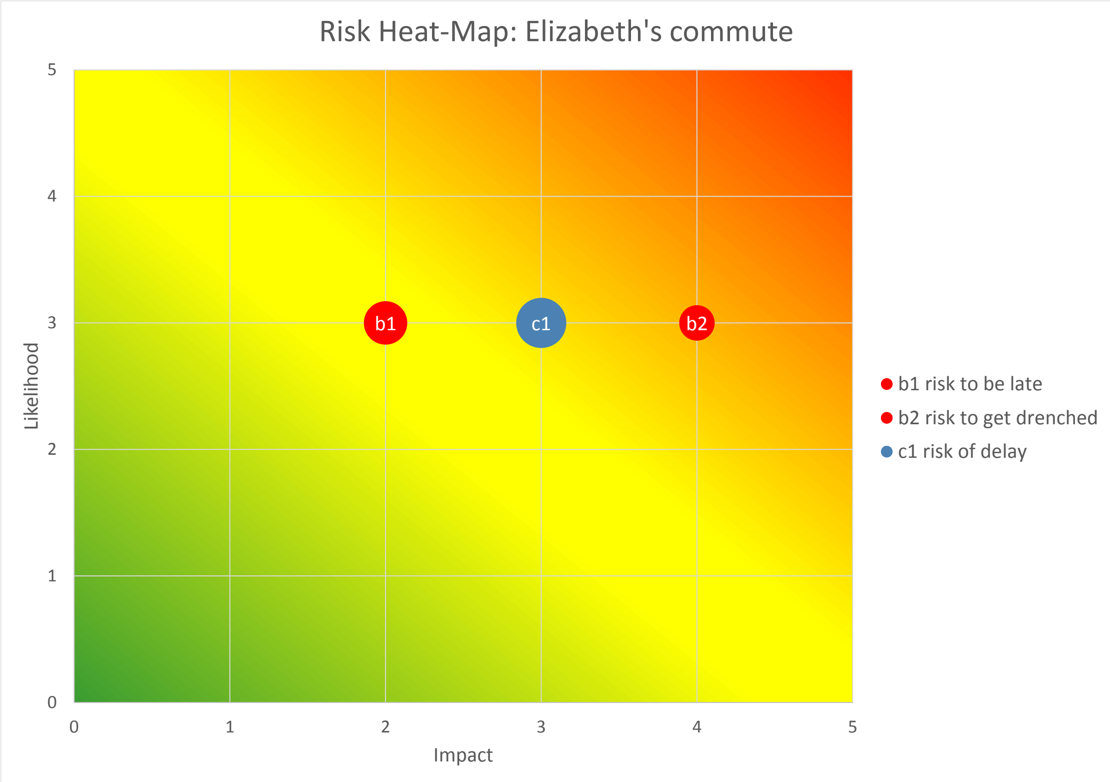
1. impact. This represents the extent of the consequences a risk might cause upon its manifestation.
2. likelihood. This is the probability that a risk occurs.
3. vulnerability. This measures how well a risk is managed.
4. velocity. This is the time it takes for a risks to manifest into consequences.

Appendix C shows full template examples for the risk analysis criteria.

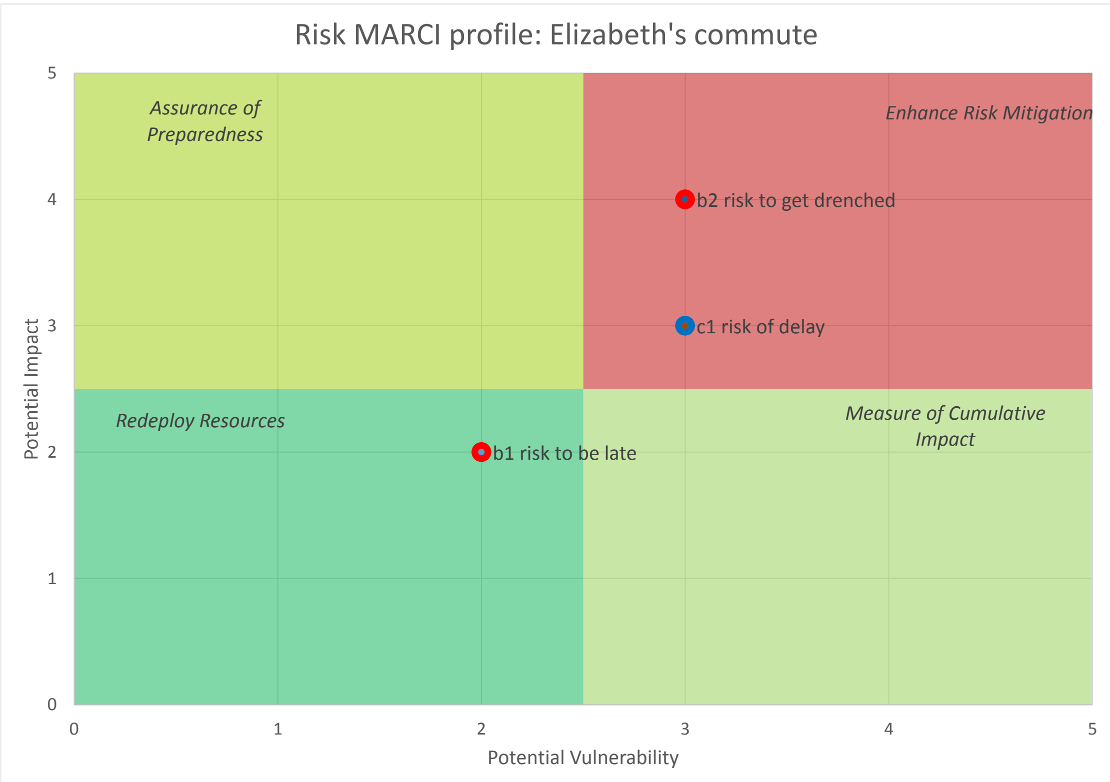
Risk evaluation

Having identified all risks and provided an assessment of its measurements allows for the creation of a risk profile through the prioritization and interactions of risks in risk portfolios. To gain overview, a heat map can be used to visualize risks in dimensions of likelihood and impact and potentially filter out risks that do not require further actions as seen in example figure 4.7a in green or yellow areas, depending on what risk level is deemed acceptable. The risks that require further action can be plotted on a MARCI (Mitigate, Assure, Redeploy and Cumulative Impact) chart, see figure 4.7b, that provides an indication of appropriate risk response. Risks in the 'Enhance Risk Mitigation' quadrant require the first attention in order to reduce or minimize their impact or vulnerability. Risks in the 'Assurance of Preparedness' quadrant have increased confidence of being managed sufficiently to reduce their vulnerability to acceptable levels. Risks in 'Redeploy Resources' require further evaluation to see if spent resources can be deployed elsewhere and 'Cumulative Impact' requires further investigation to assess the aggregate impact of a number of individually small impacting risks (i.e. if many small risks become one big risk).

Figure 4.7: Example Risk Profile



(a) Example Risk Heat-Map



(b) Example MARCI chart

Risk assessment example: Elizabeth's commute

The uncertainties identified in the last phase are used to elicit risks associated with each commute option.

Risk identification For the bike ride the duration estimation uncertainty, which originated out of the stamina capability, was investigated first and determined to potentially lead to a risk of being late. The risk of being drenched while biking, thought to seriously impact Elizabeth's representability, was distilled out of uncertainty over the weather, derived exogenously as an environmental source. The car ride was seen to risk delays, due to a traffic jam, based on uncertainty about this mornings traffic intensity. The risks were added to the Archimate diagram in figure 4.6.

Risk analysis With the risks identified, table 4.1 is created and populated. A value of one (lowest) to five (highest) is given for each criteria, based on Elizabeth's judgment, for each risk. The risk levels are calculated by multiplying impact and likelihood.

Table 4.1: Example Risk Analysis

Option	Uncertainty	Risk No.	Risk	Impact	Likelihood	Vulnerability	Velocity	Risk Level
bike-ride	duration estimation	b1	risk to be late	2	3	2	3	6
	weather	b2	risk to get drenched	4	3	3	2	12
car-ride	traffic intensity	c1	risk of delay	3	3	3	4	9

Risk evaluation Risk evaluation assists in selecting and prioritizing risks for treatment. While Elizabeth only identified three risks it still helps to visualize risks in order to make decisions on needed treatment. A heat-map is used to filter risks based on impact and likelihood as shown in figure 4.7a. The risk level, the multiplication of impact and likelihood, can be used to filter risks that demand treatment consideration and therefore a decision is required on a minimum risk level. Elizabeth, due to only having three risks, considers all risks with a risk level higher as six (yellow and red regions of heat-map), which includes them all.

These are the risks that are plotted on a MARCI chart in figure 4.7b. The MARCI chart refines risk prioritization and gives an initial evaluation of appropriate response. Elizabeth decides that risk b1, of being a little late by bike, is safe to not receive further treatment, based on its low vulnerability and impact score. Risks b2 and c1 however are key candidates for treatment.

4.5.4 Risk treatment design

Risk treatment decides on one or more options that modify the risks on options. As described in section 3.7.1 these can be categorized in the following (not mutually exclusive) strategies:

- avoidance. Avoidance of a risk can involve not choosing for an option. This is often reserved for risks that have no other treatment available on options that do have alternatives. Avoiding risks also reduces the potential for future gains which can introduce new risks.

- reduction. Reduction lowers the vulnerability to risks. Enterprises try to find a balance between the costs involved to reduce the risks with the possible gains received of performing the option. Two common ways exist that can reduce risks of an options:
  - diversification: by putting riskier options in a portfolio with options with less risk the negative consequences of risks in one option can be countered by options with more guaranteed return of value.
  - hedging: hedging requires the creation of risk mitigating options, i.e. real options, for options by investing in flexibility.
- sharing. Sharing a risk involves distributing the potential impact (loss or gain) with other parties. This is often done through contracts such as those for insurance, sub-contracting and outsourcing.
- retention. Risk retention is the planned acceptance of losses by deductibles, deliberate non-insurance and loss-sensitive plans. It is a viable strategy for risks where costs of insurance against the risk are greater than potential total losses sustained.

The risks identified in the risk assessment phase with a high impact and vulnerability are to be analyzed for possible treatments. It is advisable to look for solutions in each of the above categories to ensure a comprehensive treatment design. Of particular interest is the design of Real Options (ROs), see section 3.8, which identifies risk reductions by investment in flexibility. This creates opportunities to choose higher-risk options by mitigating risks through the offsetting, or hedging, of potential losses and gains. To date no formalized processes exist for the identification of Real Options and it is presented as a process performed mostly intuitively by case matter experts. By positioning it directly in the risk treatment process the potentially endless flexibility options can be reduced to those that have a significance to the decisions context. Real Options identification can be further supported by analyzing the categories of flexibility given in section 3.8.3. By documenting identified Real Options along with the uncertainties and risk, as mentioned earlier, a repository can be managed for future reference to ensure the real options, their requirements and effects are dealt with throughout the EA. If for example a real option is designed that can scale-down a service offered by an enterprise, the relating EA such as the IT infrastructure should also support this and it could be considered that a cloud-solution could subsequently provide this flexibility more cost effective as an in-house solution.

Risk treatment example: Elizabeth's commute

Having identified and prioritized risks for treatment, using the Heat-Map and MARCI charts, Elizabeth focuses on the two risks selected for treatment. All treatment options are considered for each risk, however risk reduction was looked at first as Elizabeth believes it has the largest potential and she enjoys being flexible.

b1 risk to get drenched Elizabeth considers to mitigate the risk of getting drenched while riding a bike by buying rain gear. She believes this allows her to cycle in bad weather conditions and remain presentable and thus present her with a flexibility. To receive this flexibility a small investment of $\$50$ is required to buy the gear. No further diversification and sharing options were identified. Avoidance entails selecting the other commute option while retention involves accepting getting drenched from time to time. Retention is estimated at experiencing 30 wet commutes per year with a time to recover from being drenched of 20 minutes. The risk treatment was modeled directly into the Archimate diagram as shown in figure 4.8. Notice that when choosing the bike ride option another choice is required between the plain bike ride or the bike ride with rain gear option, effectively adding an extra option (in magenta) to choose from that builds upon the plain option in red.

c1 risk of delay Brainstorming revealed little that could be done to reduce the delays the car ride can experience. The delays typically occur around a bridge that all feasible alternative directions to Elizabeth's office need to cross and is known to often have heavy traffic. No construction plans exist in the foreseeable future that could possibly reduce the delays and Elizabeth's office hours are fixed by her employer. Elizabeth is left with retention of the risk which entails accepting the average traffic jam, estimated as 5 minutes on each commute based on last years' traffic data.

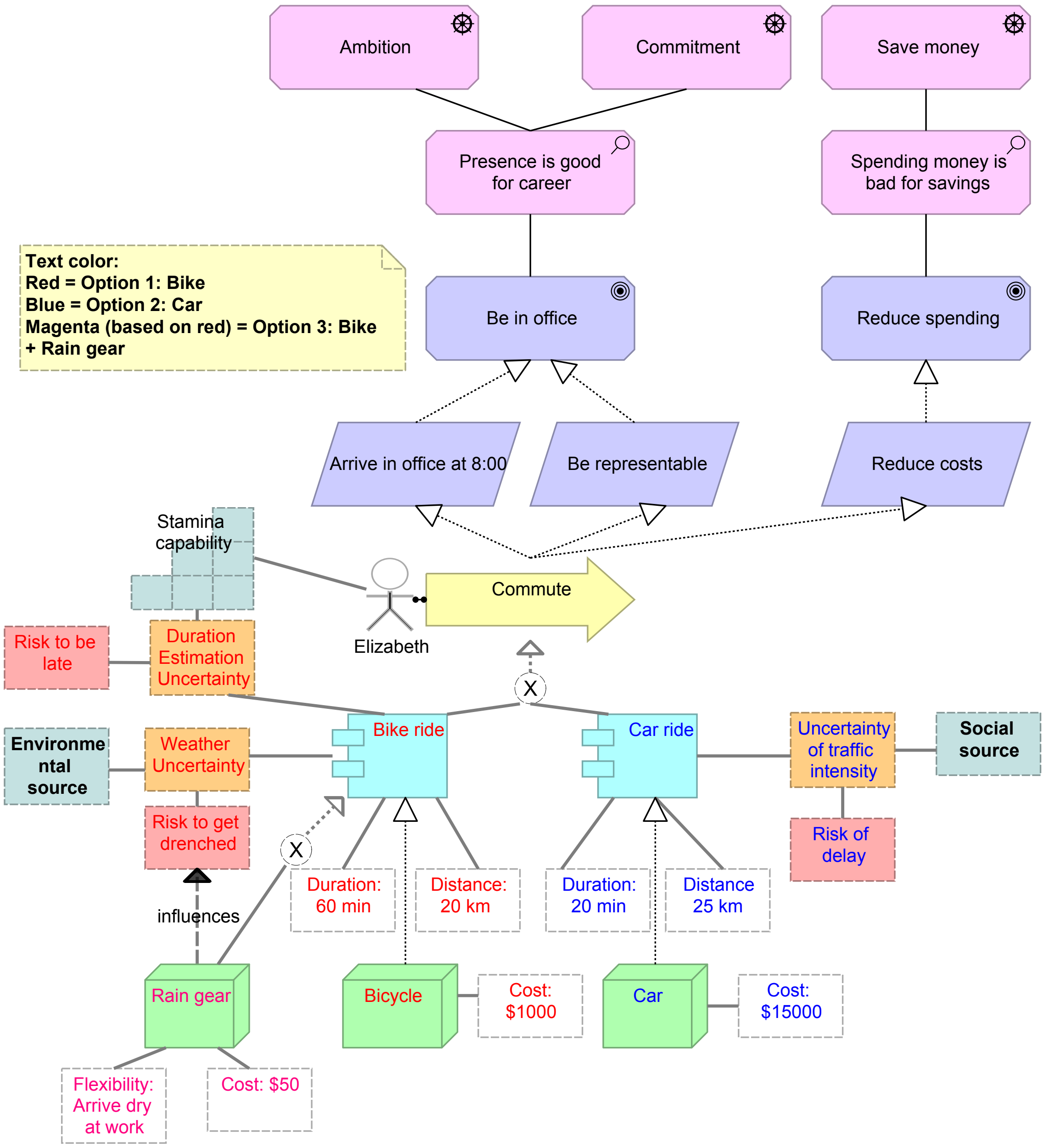


Figure 4.8: Example Archimate Risk treatment

4.5.5 Option valuation

With the options, their risks and the potential treatments identified, a valuation of each option is needed to make an informed decision. To compare different options a common attribute or a set of common attributes are required. By viewing options as investment opportunities an obvious criteria for decisions is to maximize the return of value as expressed in section 3.2. Quantifying business value is not trivial and requires predictions of the future performance of an investment, see section 3.2.1, that accounts for uncertainties. Research shows the increasing use of financial analysis techniques with a DCF analysis, explained in detail in section 3.2.1, being the most prominent (R. Pike, 1996; Alkaraan & Northcott, 2006). Options in decision making can be valued using the same financial evaluation methods as described in literature. Real Options, a special kind of option that includes an investment in flexibility can be valued using one of the many Real Option methods, see section 3.8.2, that often build upon DCF analysis. Because of its transparency this research uses the Binomial Option Pricing Model (BOPM) as proposed by Cox et al. (1979) using the Logarithmic present value approach to estimate volatility (section 3.10.2) under the Market Asset Disclaimer (MAD) assumption from Copeland and Antikarov (2003) as explained in sections 3.8.2 and 3.10.

Option valuation example: Elizabeth's commute

The risk treatment phase resulted in three options, two options without and one with real-option, requiring valuation. To be able to compare the options, additional assumptions are required that have been added as attributes to the Archimate diagram, see figure 4.9. Table 4.2 shows an overview of the attributes required to create the DCF for the bike ride and table 4.3 the attributes for a commute by car. To express the duration of a commute in terms of value Elizabeth estimates her free time, as the commute is on top of work-hours, as $20 per hour. The average rain days, its distribution and volatility could be retrieved online from a weather website, the same was done for the average traffic delays. In the gym Elizabeth was able to measure her average cycling speed multiple times on a comparable route and calculate the volatility and distributions also shown in table 4.2. It is important to note that the systematic risk of the bike-ride was considered higher, in line with the risk analysis made in the previous steps, and therefore the risk-adjusted discount rate of the bike-ride on top of Elizabeth's cost of capital was set slightly higher.

Table 4.2: Bike-ride Assumptions Example

Attribute	Value	Unit	Distribution	Parameters
starting salary	50000.00	$/year		
salary increase	8	percent	normal	$\sigma = 0.15$
duration per commute	60	min		
distance per commute	20	km		
average speed	20	km/h	normal	$\sigma = 1.00$
commutes per day	2	times		
workdays per year	240	days		
commutes per year	480	times		
commute-time per year	28800	min/year		
estimated cost free time per hour	20.00	$/hour		
estimated cost free time per minute	0.34	$/min		
estimated duration cost per year	9600	$/year		
recovery time from being drenched	20	min		
estimated recovery cost	6.67	$		
average wet commutes per year	30	days	normal	$\sigma = 0.80$
average recover cost per year	200.00	$/year		
cost of capital	8	percent		
risk-adjusted discount rate	13	percent		

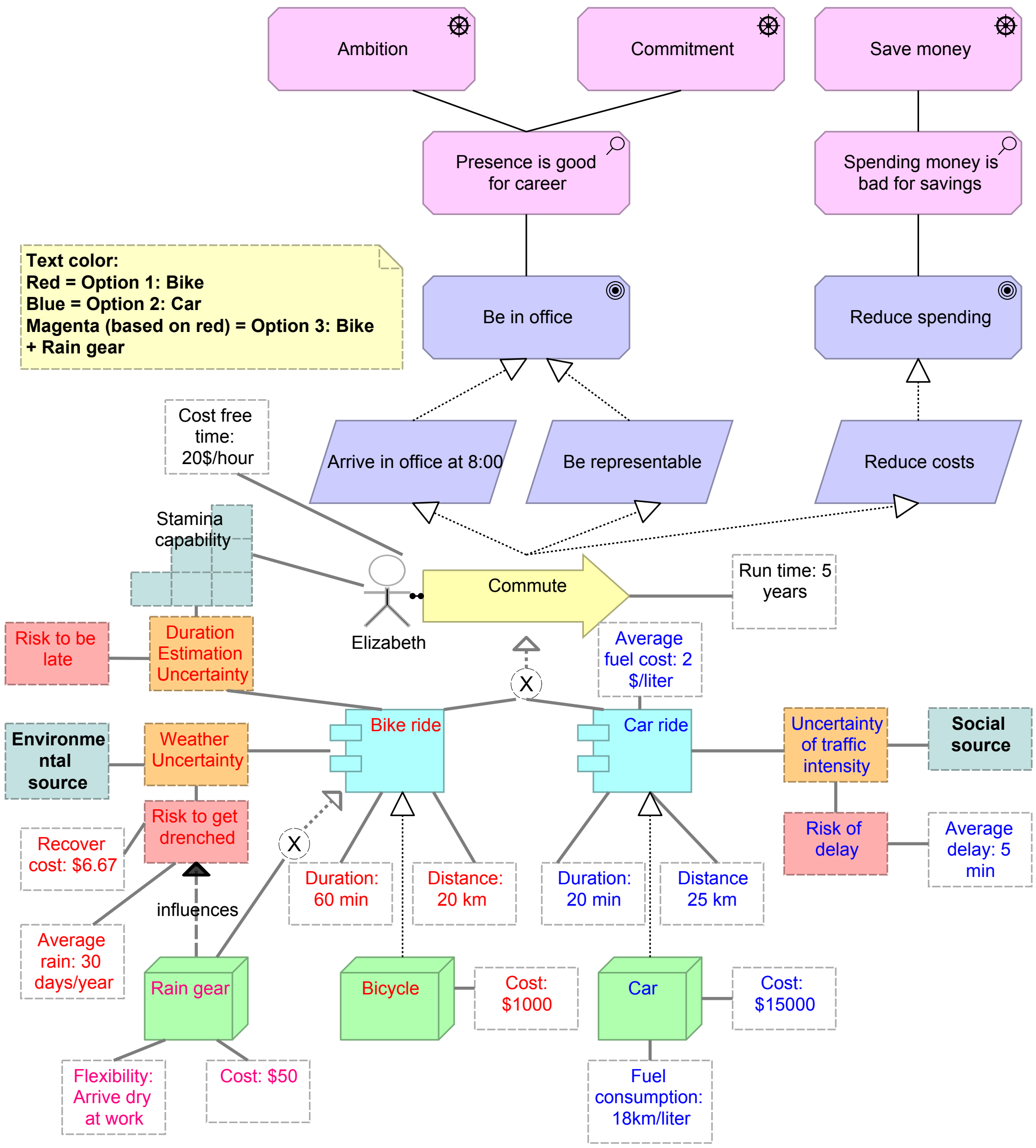


Figure 4.9: Example Archimate Risk treatment

With the attributes expressed as values a DCF analysis for both main options was possible as shown in table 4.4 and table 4.5.

To account for the identified risks a Monte Carlo simulation is run on the DCF simulating possible inputs according to risk distribution models over multiple iterations to establish a simulated average NPV value. Various tools exist that make running Monte-Carlo simulations easy with the advantage of being able to test various distributions and define correlations efficiently. Elizabeth uses Palisade's @Risk in combination with Microsoft's Excel to run the simulation with the output shown in figure 4.10 and figure 4.11. As can be seen the new estimated average NPV values are $\$183,190.36$ for the bike-ride versus a $\$193,333.06$ for the car-ride. Next is to value the Bike-ride option with the real option flexibility of having rain gear. Because the real option can be exercised at any time (and thus it behaves as an American option) it is chosen to value the option using the binomial option pricing model described by (Cox et al., 1979). Due to a lack of historic data or proxies the project without flexibility is deemed the best unbiased estimate of the projects market value as per the MAD assumption. This enables the logarithmic present value approach to estimate volatility, as extended on by Mun and explained in section 3.10.2. It collapses all future cash flow estimates into two sets of

Table 4.3: Car-ride Assumptions Example

Attribute	Value	Unit	Distribution	Parameters
starting salary	50000.00	\$/year		
salary increase	8	percent	normal	$\sigma = 0.15$
duration per commute	20	min		
distance per commute	20	km		
average speed	75	km/h	triangular	$min. = 65$, $max. = 100$
commutes per day	2	times		
workdays per year	240	days		
commutes per year	480	times		
commute-time per year	9600	min/year		
estimated cost free time per hour	20	\$/hour		
estimated cost free time per minute	0.34	\$/min		
estimated duration cost	3200	\$/year		
average cost fuel	2.00	\$/liter		
fuel consumption small car	18	km/liter		
average fuel cost per commute	2.78	\$		
current fuel cost per year	1333.33	\$/year		
average fuel price increase	3%	annually	normal	$\sigma = 0.10$
cost of capital	8	percent		
risk-adjusted discount rate	12	percent		

present values, a set with the cash flows discounted to the first time period and a set discounted to the present time period. A return ratio can be calculated by taking the logarithm of the ratio of the sums of the free cash flows' present value at time period one and time period zero. Table 4.6 shows this calculation for the Bike-ride. Through Monte Carlo simulation on the DCF a forecasting distribution of one period returns on the return ratio can be established. The volatility σ is defined as the standard deviation of the return ratio with $\sigma = 0.4545$. Mun extended the method by duplicating the cash flows and performing the Monte Carlo simulation only on the numerator cash flows while keeping the denominator cash flow values constant and reduces the measurement risks of auto-correlated cash flows and negative cash flows (Mun, 2002). The results of the Monte Carlo simulation are shown in figure 4.12.
Figure 4.12 shows the standard deviation of the return ratio to be 0.4545 which defines the volatility σ and is used in the binomial option pricing model as input to calculate the up (u) and down (d) movements shown in equation (4.1).

$$\begin{aligned} u &= e^{\sigma\sqrt{t}} = e^{0.4545\sqrt{1}} = 1.5753 \\ d &= e^{-\sigma\sqrt{t}} = \frac{1}{u} = 0.6348 \\ \text{where } u &= \text{increase in price for one period} \\ d &= \text{decrease in price for one period} \\ \sigma &= \text{volatility} \\ t &= \text{binomial time period} \end{aligned} \tag{4.1}$$

With the up and down factors calculated a binomial lattice can be constructed using the projects NPV as a starting point in table 4.7.

By using backward induction on the binomial lattice in table 4.7 we can add the value of flexibility to the asset value. To determine the value of the flexibility Elizabeth determines a

Table 4.4: Discounted Cash flow Bike-ride Example

Year	2015	2016	2017	2018	2019	2020
Period	0	1	2	3	4	5
Initial cost ($)	1000.00					
Duration cost ($)		9600.00	9600.00	9600.00	9600.00	9600.00
Recovery cost ($)		200.00	200.00	200.00	200.00	200.00
Salary increase		8.00%	8.00%	8.00%	8.00%	8.00%
Salary ($)		54 000.00	58 320.00	62 985.60	68 024.45	73 466.40
Cash flow ($)	(1000.00)	44 200.00	48 520.00	53 185.60	58 224.45	63 666.40
Discounted Cash flow ($)		39 115.04	37 998.28	36 860.29	35 710.14	34 555.57
Discount rate	13.00%					
Net present value ($)	183 239.33					

Table 4.5: Discounted Cash flow Car-ride Example

Year	2015	2016	2017	2018	2019	2020
Period	0	1	2	3	4	5
Initial cost ($)	15 000.00					
Duration cost ($)		3200.00	3200.00	3200.00	3200.00	3200.00
Fuel price increase		3.00%	3.00%	3.00%	3.00%	3.00%
Fuel cost ($)	1333.33	1373.33	1414.53	1456.97	1500.68	1545.70
Salary increase		8.00%	8.00%	8.00%	8.00%	8.00%
Salary ($)		54 000.00	58 320.00	62 985.60	68 024.45	73 466.40
Cash flow ($)	-15000.00	49 426.67	53 705.47	58 328.63	63 323.77	68 720.71
Discounted Cash flow ($)		44 130.95	42 813.67	41 517.17	40 243.40	38 993.97
Discount rate	12.00%					
Net present value ($)	192 699.16					

lower bound value, made possible by the rain gear, that the value of the bike-ride will not drop below. To estimate this lower bound value the DCF analysis of the bike-ride was used with the following adjusted parameters:

1. The rain gear was seen to at least be effective in $2/3$ of the commutes and therefore reduce the wet commute assumption to an average of 10 days.

2. To provide a lower bound, the average speed was reduced to $10\ km/h$.

This produces an NPV of $\$149,892.87$ that represents a value the bike-ride cannot drop below. Section 4.5.5 calculates the risk neutral probability and is used to calculate the binomial value by starting at the terminal nodes of table 4.7 and backtracking to the first node. In the terminal nodes, due to not having an up or down node relative to the current node, the maximal value is chosen out of the option value or the terminal asset value. For each subsequent node the binomial value calculated in equation (4.2) is compared with the option exercise value and again the highest value is selected. Since Elizabeth determined the option exercise value to be $\$103,154.08$ the binomial lattice is calculated through backward induction using

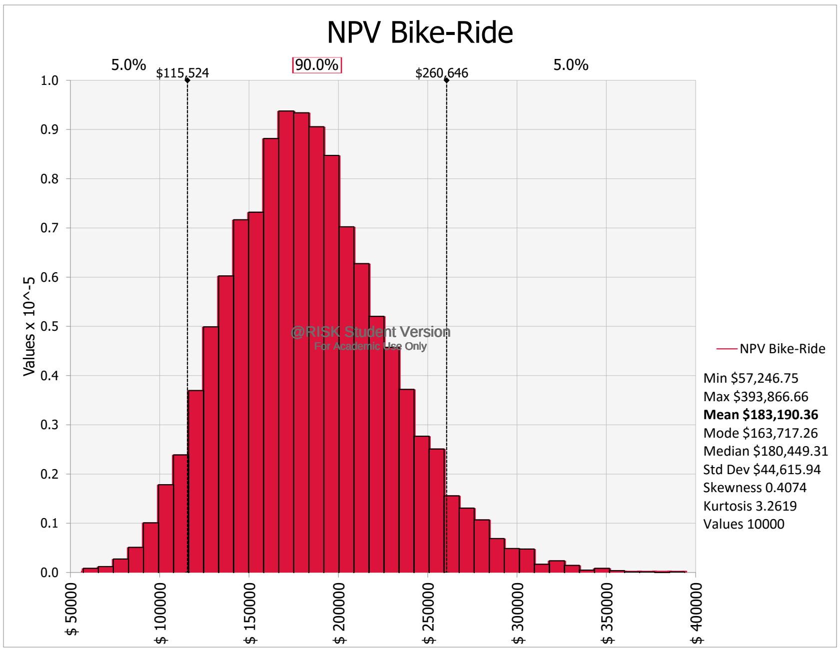


Figure 4.10: Example Monte Carlo NPV estimation Bike-ride

$max(C, \$103,154.08)$ giving table 4.8 with executed options highlighted in a bold typeface.

$$
\begin{aligned}
p &= \frac{e^{(r-q)t} - d}{u - d} = \frac{e^{(13\%-0)1} - 0.6348}{1.5753 - 0.6348} = 0.5359 \\
\text{where } p &= \text{probability of up move} \\
r &= \text{risk free interest rate} \\
q &= \text{dividend yield of underlying} \\
t &= \text{binomial time period} \\
u &= \text{up factor} \\
d &= \text{down factor}
\end{aligned}
$$

$$
\begin{aligned}
C &= e^{(-rt)}((p * C_u) + ((1-p) * C_d)) \\
\text{where } C &= \text{binomial value current node} \\
r &= \text{risk free interest rate} \\
t &= \text{binomial time period} \\
p &= \text{probability of up move} \\
C_u &= \text{up node value relative to current node} \\
C_d &= \text{down node value relative to current node}
\end{aligned}
\tag{4.2}
$$

As can be seen in table 4.8 the rain gear option increases the NPV of the bike-ride in present time to $\$203,231.53$. The rain-gear flexibility therefore is valued as $\$203,231.53 - \$183,239.61 - \$50 = \$19,941.92$ and the rain gear was well worth its $\$50$ investment.

4.5.6 Decision making

With all options valuated and risk adjusted an informed decision can now be made. Decisions are made using criteria, the rules or standards to base a decision on. The requirements, as identified in section 4.5.1 provide the base for the criterion. A decision strategy determines how the criteria are used to reach a decision. Viewing and valuating each of the options as

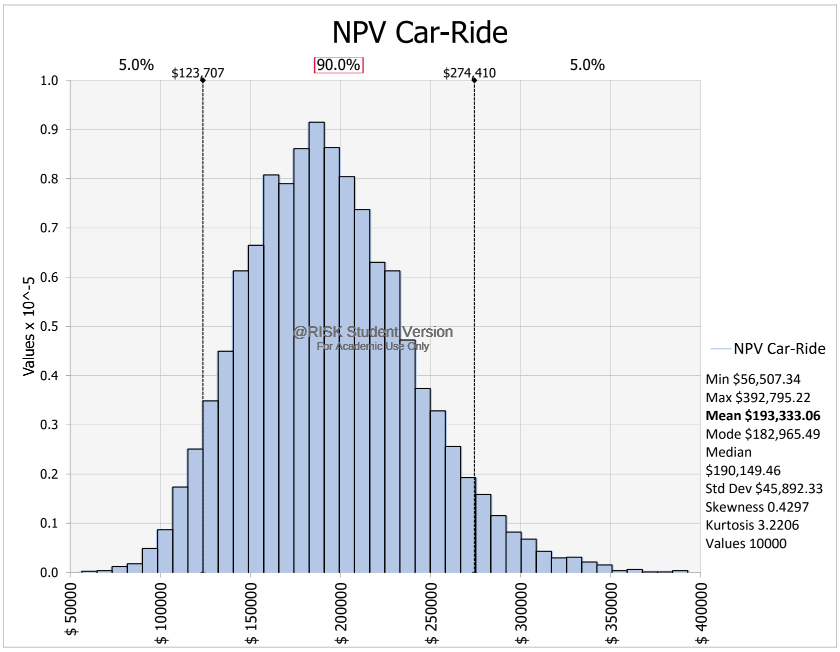


Figure 4.11: Example Monte Carlo NPV estimation Car-ride

investment opportunities creates a lexicographic strategy using a value maximization criterion. If other criteria are used, they should be considered for inclusion in the valuation of the option in the previous step. If not quantifiable or otherwise deliberately excluded they can, however, still be valuable criteria for decision making but great care is required in the selection of the strategy and its documentation.

Decision making example: Elizabeth's commute

Valuation of options has left Elizabeth with the following decisions, between a bike and a car-ride and between a bike and bike-ride with rain gear. Reflecting back on the requirements it is seen that a value maximization criterion through the assumptions (cost of free-time and average speeds) made earlier also relates indirectly to the requirements of cost reduction, representability and timeliness. Based on the current (and deliberately limited) information Elizabeth would decide to invest in a bicycle with rain gear. If the decision is part of a greater decision process, e.g. to compare jobs, the decision making output from this decision can be used as input in job selection.

Table 4.6: Example Commute Bike-ride Logarithmic Present Value Approach

Time period	Cash Flows	Present Value at Time 0	Present Value at Time 1
0	$-1000.00	$\frac{\$-1000.00}{(1+13\%)^0} = \$-1000.00$	-
1	$44200.00	$\frac{\$44200.00}{(1+13\%)^1} = \$39115.04$	$\frac{\$44200.00}{(1+13\%)^0} = \$44200.00$
2	$48520.00	$\frac{\$48520.00}{(1+13\%)^2} = \$37998.28$	$\frac{\$48520.00}{(1+13\%)^1} = \$42938.05$
3	$53185.60	$\frac{\$53185.60}{(1+13\%)^3} = \$36860.29$	$\frac{\$53185.60}{(1+13\%)^2} = \$41652.13$
4	$58224.45	$\frac{\$58224.45}{(1+13\%)^4} = \$35710.14$	$\frac{\$58224.45}{(1+13\%)^3} = \$40352.46$
5	$63666.40	$\frac{\$63666.40}{(1+13\%)^5} = \$34555.57$	$\frac{\$63666.40}{(1+13\%)^4} = \$39047.80$
Sum		$183239.33	$208190.44
Return ratio	$\ln(\frac{\$208190.44}{\$183239.33}) = 0.1277$		

Table 4.7: Example Binomial lattice for 5 period price evolution of Bike-ride with rain gear option

0	1	2	3	4	5
183 239.33	288 665.83	454 748.64	716 386.58	1 128 556.92	1 777 867.93
	116 317.04	183 239.61	288 665.83	454 748.64	716 386.58
		73 835.85	116 317.04	183 239.61	288 665.83
			46 869.60	73 835.85	116 317.04
				29 751.94	46 869.60
					18 885.97

Table 4.8: Example Decision lattice for 5 period option value evolution of Bike-ride with rain gear option

0	1	2	3	4	5
203 231.53	297 021.44	457 021.08	716 386.58	1 128 556.92	1 777 867.93
	155 725.67	201 118.90	294 242.01	454 748.64	7 316 386.58
		149892.87	153 751.03	196 922.62	288 665.83
			149892.87	**149892.87**	**149892.87**
				149892.87	**149892.87**
					149892.87

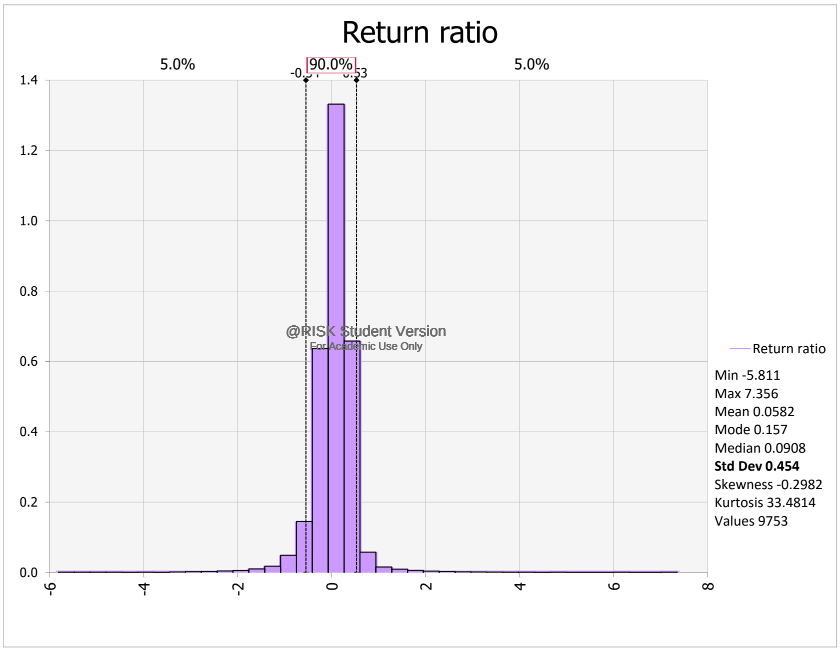


Figure 4.12: Example Bike-ride with rain-gear Return ratio simulation results

Table 4.9: Decision Making example

Option	Attribute	Value
bike-ride	value	$183239.61
bike-ride with rain gear	value	$203231.53
car-ride	value	$192699.16

4.6 TOGAF, Archimate and FEUD

Although FEUD is generic enough to be used for any decision making, its ability to directly address and deal with uncertainty makes it particularly well suited for use in Enterprise Architecture Frameworks. In this chapter an example is given how it can be combined with TOGAF and modeled using the Archimate standard. Figure 4.4 shows the generic decision making life-cycle, the following chapters outline each phase of the life-cycle in-order. In practice it is expected that subsequent phases can return to previous phases and are thus performed iteratively.

4.6.1 FEUD EA decision investigation

Decisions are required in any phase of EA development and are made to directly or indirectly fulfill requirements or can be caused by constraints. Decisions made can also be a consequence of earlier decisions and thus can be represented in a decision-chain. This decision-chain often runs across many EA dimensions and the target EA represents the results of this EA decision-chain. Decisions often choose between investments on alternatives or in the case of only one alternative whether to go ahead with, delay or abandon an investment. The Requirements Engineering (RE) process will typically initiate a decision making cycle and requires decision alternatives are inline with stakeholder desires. Therefore, RE itself is a decision driven process impacted by a high degree of uncertainty (Aurum & Wohlin, 2005).

TOGAF EA decision investigation

TOGAF incorporates the Architecture Development Method (ADM). Each phase in ADM can elicit new requirements and decisions are made across all TOGAF ADM's phases, below we briefly discuss the types of decisions in each phase. Note that TOGAF's ADM, see figure 3.1, is iterative over the whole process, between the phases and within phases. The decisions made in each phase therefore can be, and likely are, the result of many iterations between different phases.

ADM preliminary decisions In the preliminary phase decisions are made on what EA method(s) are used (and which not), who will or will not drive the architectural change and its needed participants and the scope of the EA. Here the value of the EA efforts themselves are analyzed and the need for FEUD is evaluated.

ADM architecture vision decisions The architecture vision phase initiates a single architecture development cycle and starts with formulation of a vision of the capabilities and business value to be delivered as part of this project. This motivation can consist of stakeholders, concerns, business requirements, goals, drivers and constraints. FEUD intents to document and support decisions on and between aforementioned motivational elements. The Archimate motivational extension provides effective means of visualizing these elements but in its current version does not have provisions to display alternatives and choices. Figure 4.13 gives a meta-model extension of how decisions can be modeled with Archimate's motivation extension (The Open Group, 2013).

ADM Business architecture decisions The business architecture phase establishes the value proposition, business strategy and the working model of the enterprise. The scope of the enterprise under architecture was defined in the previous phases. If an existing business architecture exists for this enterprise, it can be used to create the baseline architecture if no descriptions exists these are to be gathered and documented first. A target business architecture is designed by aligning existing business architecture components, when possible, to previously established

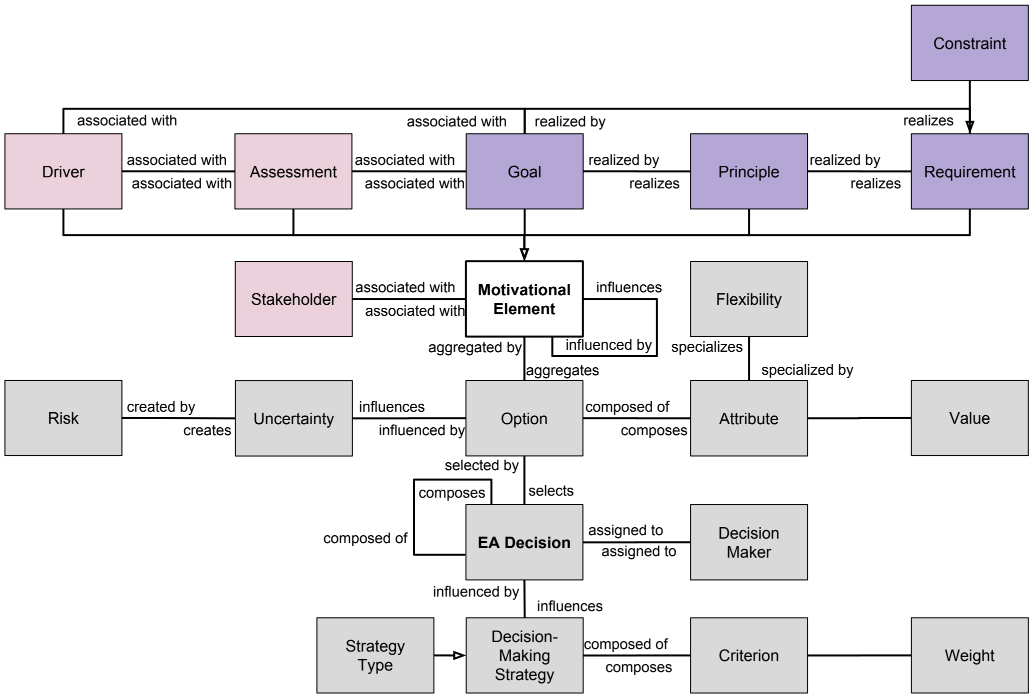


Figure 4.13: FEUD Archimate Motivation Conceptual-Model

requirements or, when not, by creating new components. Archimate allows description of business architecture using the following concepts:

- Active structure concepts. These are the entities that perform behavior in business processes or functions and can be individuals, groups (organizational units) or resources such as business units or departments. Typical decisions on active structure relates to who or which groups will perform what behavior and in what capacity and location.

- Behavioral concepts. Service orientation models functionality offered to the environment as independent business services or internally as supporting processes or functions within the organization. Decisions are made on what services to offer, which business functions and which processes support which business services.

- Passive structure concepts. These are the business objects that are created and/or manipulated by the business processes or functions. Choices are needed between different objects that are required to support business services, the products that are offered and how business objects are represented.

Figure 4.14 shows a meta-model of EA business decisions in Archimate.

ADM information systems architecture decisions The information systems architecture phase designs a target data architecture and application architecture inline with the target business architecture. Decisions on the business architecture therefore create opportunities and constraints in the information systems architecture. Reversely, the information systems architecture can create new constraints and opportunities that requires revisiting earlier decisions and potentially create new alternatives, inline with strategic alignment models (Henderson & Venkatraman, 1993). Archimate's application layer provides concepts, many inspired by the UML 2.0 standard, that can be used to both describe a high-level data architecture as well as its application architecture (The Open Group, 2013). Like the business architecture Archimate describes the application architecture with three concepts:

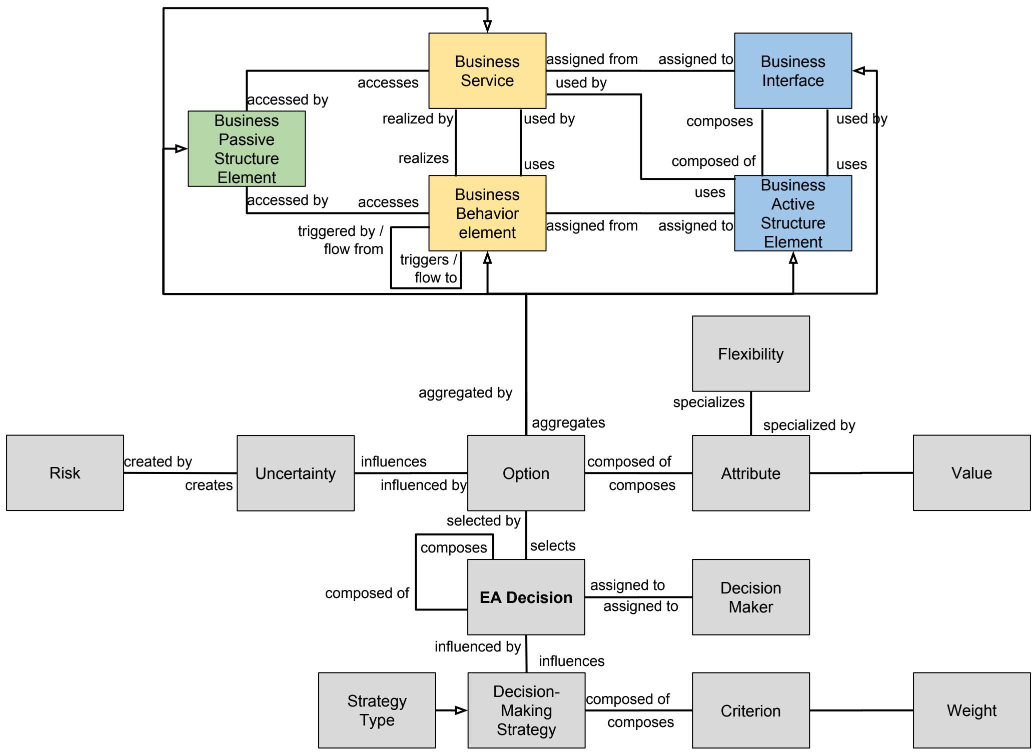


Figure 4.14: FEUD Archimate Business Conceptual-Model

- Active structure concepts. These are the entities that perform behavior such as application components, collaborations and or interfaces. The typical decisions on active structures relates to which application or information system can create an interface that can be utilized in services (=behavioral concept) offered to the business layer.

- Behavioral concepts. Like business layer behavioral concepts these are divided in the internal behavior, the functions interactions and collaborations of applications and information systems, and external behavior, which is be offered as a service. Decisions are made on what services are provided and how using which behavior.

- Passive structure concepts. These are the data objects and can be seen as a representation of business objects. Information entities, for the information architecture, can be modeled as data objects.

Figure 4.15 shows a meta-model of application decisions in Archimate.

ADM technology architecture decisions The technology architecture describes the logical software and hardware capabilities that are required to support the deployment of business, data and application services (The Open Group, 2011). Like the business and application layers, Archimate describes it using the same concepts:

1. Active structure concepts. These are the structural aspects of a system that provide execution context for artifacts or the artifacts that execute on the system such as system software and devices, the two types of a node. It also models the infrastructure elements necessary to exchange information between nodes such as networks and communication paths. Decisions on active structure concepts often chooses between vendors, standards and technology trends.

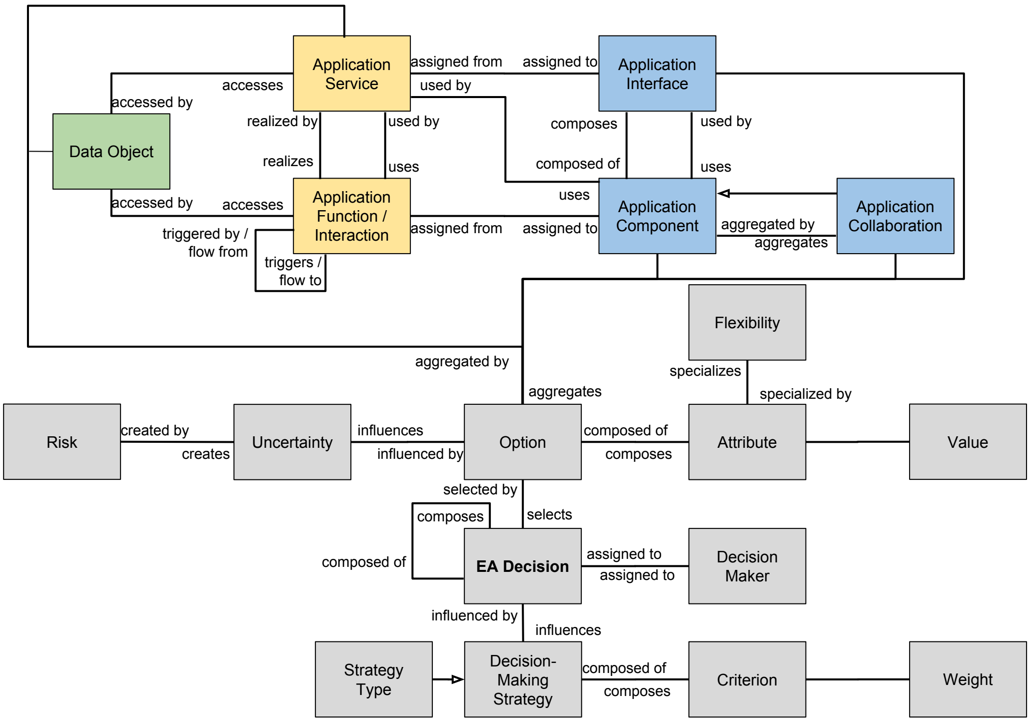


Figure 4.15: FEUD Archimate Application Conceptual-Model

2. Behavioral concepts. Similar to the other Archimate layers these are divided in internal and external behavior of nodes in terms of services. Decisions between alternatives decide on what behaviors are required or if a behavior is required from active structure concepts.

3. Passive structure concepts. A physical piece of information used by or in an system or software process such as an executable or data entity.

Figure 4.16 shows a meta-model of technology decisions in Archimate. Archimate 2.1 includes the implementation and migration extension that supports documentation, shown in figure 4.17, of the following TOGAF phases.

ADM opportunities and solutions decisions The opportunities and solutions phase identifies the projects needed to transform the current architecture to the desired target architecture, typically through a gap analysis, and documents them in an initial architecture road map. Incremental transition architectures, defined by Archimate as plateaus between a baseline and target, can be identified in order to deliver continuous business value while receiving early feedback and a better ability to manage risks. Decisions on project alternatives, transitions and planning provide options for decision makers.

ADM migration planning decisions Migration planning prioritizes projects and creates an implementation and migration plan by creating deliverables and work packages. Decisions are made to plan and prioritize projects in the bigger context of all enterprise activities.

ADM implementation governance decisions Implementation governance describes the responsibilities involved in the previously identified projects. Decisions are made on who owns a project by assigning Archimate business roles to work packages.

Architecture change management decisions The goal of architecture change management is to monitor and ensure the architecture achieves its intended business value. Decisions

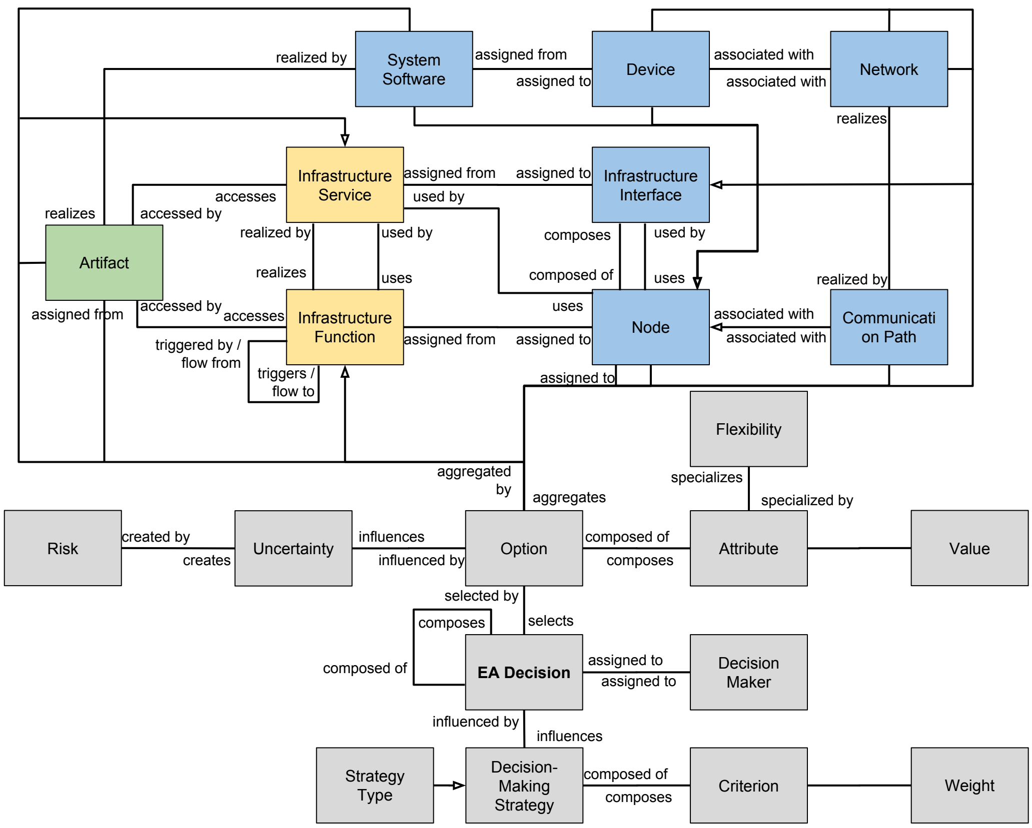


Figure 4.16: FEUD Archimate Technology Conceptual-Model

with options allow rapid adaptation to progressing and new unfolding events and create an organization with a greater flexibility. To be able to react effective monitoring is required, particularly around these options, but also a structure that allows those governing to effect changes. All the previously documented architecture elements can need such control, those elements that have options designed for are required to have controls in place.

4.6.2 FEUD Uncertainty identification

Pursuant to section 3.4 on uncertainty, FEUD's uncertainty identification process identifies uncertainty by looking at several sources that are categorized broadly in endogenous, or internal, and exogenous, or external, types.

Endogenous uncertainty can be further specified by looking at the capabilities that are required in the EA effort and potentially provide grounds for uncertainty. To understand these required capabilities a capability maturity framework, as explained in section 3.5, can provide an overall capability structure. To elicit specific capabilities, as EA efforts can be expected to require capabilities specific to the context (e.g. industry), chosen business infrastructure (e.g. out or in-sourcing), application architecture (e.g. SOA) and technologies used, practitioners can utilize expert knowledge and industry best practices. The uncertainty is discovered by assessing the current capability maturity and estimating required capability maturity for the EA assets and EA transition. Capability maturity lower than the expected required capability maturity can lead to adverse risks whereas a capability higher has opportunity for developing a positive risk. Capability maturity in EA should typically be assessed by the enterprise architects in cooperation with domain experts.

Exogenous uncertainties are sourced outside an enterprise. By utilizing environmental business analysis frameworks, such as those described in section 3.6, a structured and compre-

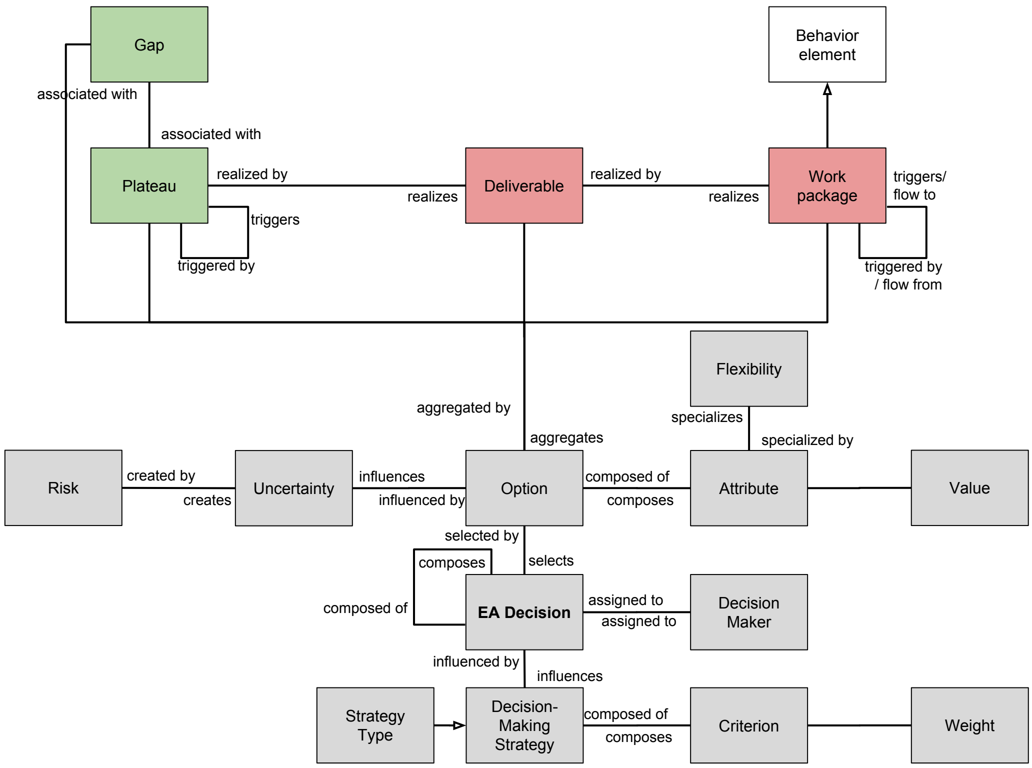


Figure 4.17: FEUD Archimate Implementation Meta-Model

hensive analysis can be performed that captures uncertainties from each environmental factor. Because of its focus on external factors and its widespread use, a PESTLE analysis as described in section 3.6.1 was selected for initial analysis in FEUD. This however does not dictate against use of other frameworks such as SWOT or Porter's five forces model instead of or in combinations with PESTLE. In fact, industry analysts typically can give an overview of trends in a particular sector using a preferred method and executives along with upper management then must determine how trends affect their enterprise.

If no uncertainties are found, or uncertainties are chosen to be ignored, the decision cycle can take a short-cut to the option valuation phase.

TOGAF Uncertainty identification

EA decisions, as outlined in the previous chapter, are made throughout the EA life-cycle. By viewing the EA as a series of decisions, each decision can be optimized. EA deals with uncertainty and therefore decisions in an EA are made under a variety of uncertainty. By recognizing the uncertainty that can influence a particular option and modeling it directly with Archimate several stakeholders can communicate about the uncertainty experienced from their perspectives and identify how it relates to others.

Endogenous uncertainty, sourced from capabilities, can be aligned with the capability based planning initiatives in TOGAF. Recent additions to Archimate have proposed capability planning modeling. Different types of decisions require different capabilities. For example, a decision on the business dimension to out-source can require a vendor management capability and cause business performance related uncertainties. A decision on a load-balancer in the technology dimension can be evaluated through capabilities set out in the ISO 14508 (Common Criteria) standard and create security related uncertainty.

Exogenous uncertainty, sourced from the environment, although found in the same PESTLE categories can have different affects across the EA. For example, a potential bankruptcy of a partner company can cause significant risk in the business layers. If this partner also supplied infrastructure equipment the risks manifest in the technology layer but could have effect on the application and business layers.

4.6.3 FEUD Risk assessment

Building upon ISO 31000:2009 FEUD includes a comprehensive risk assessment framework that includes risk identification, analysis and evaluation processes and recommended tools. Due to the generic design of the ISO 31000:2009 it is expected these can be utilized together with most established enterprise risk management methodologies.

TOGAF Risk assessment

TOGAF's risk management practices and recommendations are currently limited, but are compatible or can be replaced with ISO 31000:2009 making them compatible with FEUD. A extension for risk management and security modeling in Archimate exists that can be used to display and model risks. It is expected that FEUD is compatible with these and can leverage its concepts. Because risks manifest throughout an EA, and its effects can affect all other dimensions, FEUD recommends to centrally deal with ERM as shown in the adapted TOGAF ADM structure in figure 4.18. A central risk repository would make risks identified in one TOGAF phase accessible in other phases. Since risks are not necessarily contained in one EA dimension it is needed to deal with them holistically in order to manage root causes and effects.

4.6.4 FEUD Risk treatment design

FEUD includes support for the design of risk treatments and categorizes these broadly into avoidance, reduction (diversification and hedging), sharing, retention strategies. Special attention was put to a hedging treatment using Real Options as it makes higher risk investments possible through the deliberate design of flexibility.

TOGAF Risk treatment design

TOGAF does not describe risk treatments and leaves this to the practitioners and ERM models. As seen in figure 4.18 FEUD prescribes a central role for ERM which includes the design of treatments. A central repository of risks and treatments can support the organization in future efforts and new identified risks. Treatments for risks are also seen to span the entire EA and therefore should not be dealt with from the silo of one EA dimension but deserve a central role in TOGAF.

4.6.5 FEUD Option Valuation

Valuating options is an attempt to quantify options on attributes in order to make informed decisions. FEUD recognizes many financial evaluation methods exist and provides the structure to use these within a decision-making framework. These financial frameworks typically evaluate on business value, weighing costs against revenue in order to provide a positive or negative investment advice. Because uncertainty is such an important aspect of EA decision-making FEUD was build around Real Option Valuation in order to intrinsically support flexibility with the goal of enticing Enterprise Agility.

TOGAF Option Valuation

Because TOGAF does not contain a decision-making view it does not structurally prescribe valuation methods. FEUD intends to fill this gap by including financial evaluation methods

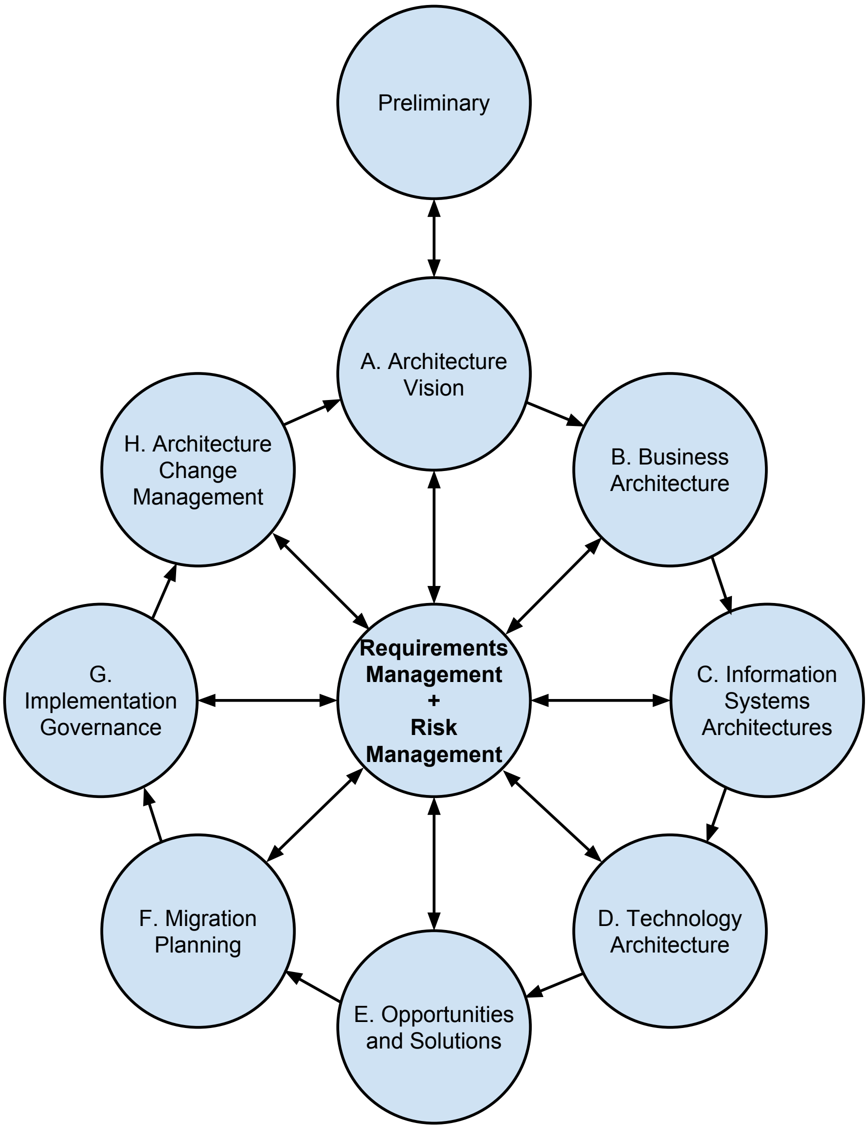


Figure 4.18: TOGAF ADM + ERM

explicitly in the process. Because EA starts more abstract and is expected to iteratively become more concrete it is expected that option valuation also follows this same line.

4.6.6 FEUD Decision making

FEUD recognizes EA decisions can be made using various strategies as proposed in Plataniotis, Kinderen, and Proper (2012) and the decision process is broadly categorized in compensatory and noncompensatory strategies. The decision strategy used is expected to depend on the type of decision to be made but also on the enterprise culture, the decision-makers and stakeholders and the size of investment involved. FEUD can align with governance frameworks existing in the organization. The governance frameworks provide controls and direction and distribute responsibilities among stakeholders. FEUD aims to enhance governance by providing a documented and repeatable process for making decisions.

TOGAF Decision making

TOGAF describes an architecture governance framework that includes IT governance and corporate governance. Guides exist that map TOGAF to the COBIT IT governance framework controls. FEUD aims to support these governance frameworks and their integration into TOGAF.

4.6.7 FEUD Archimate meta-model

FEUD introduces several new concepts to EA modeling. In the example these concepts were modeled using a make-shift notation as extensions are required to the base Archimate meta-model. While it is beyond the scope of this exploratory research to propose a new meta-model this research proposes modeling of the following concepts:

- Option: options consist of other EA components. These components are already in the Archimate language and can be found on every dimension. As such an option aggregates Archimate elements but can also have specific attributes that only relate to the option.
- Decision: decisions represent the choice of an option. As such its 'selection' relationship with options is currently difficult to express with existing Archimate relationships and requires a (exclusive-or) junction currently used for dynamic relationships (flows or triggers). In practice in a typical EA different EA models are created to represent different options and ultimately one is chosen for implementation while the rest is discarded. FEUD demonstrates the value of documenting this decision which requires previously discarded EA models to stay available in the documentation. EA decisions relate or result to other decisions, a successful EA decision-making view should capture this chain of decisions across an EA.
- Risk: a risk overlay has been proposed to Archimate described in a white-paper by the Open Group (Band et al., 2014). FEUD's risk concepts are expected to be mapped directly to the risk mappings described in above white-paper. Band et al. (2014) states "a risk is a quantification of a threat, and as such it maps most naturally to an assessment in ArchiMate. Because of the central role of this concept in enterprise risk management, the proposal is to define the risk concept as a specialization of an assessment."
- Uncertainty: uncertainty is a new concept to Archimate. They are the results of an assessment to an enterprise's capabilities and the external business environment. Like risks, uncertainty can be modeled explicitly in Archimate by specializing an assessment component.
- Capabilities: recommendations for capability extensions to Archimate exist (Papazoglou, 2014). FEUD's capabilities should be in-line with these extensions but further research is required to demonstrate this and ensure they are in-line with enterprise capability maturity and business maturity frameworks as described in section 3.5.
- Business environment: the business environment in FEUD is seen as a source of uncertainty in the same way capabilities can be a source of internal uncertainty in the enterprise. While business analysis approaches are plenty, no EA modeling standards currently exist that explicitly models these sources. A mapping to business analysis frameworks as demonstrated in chapter 5 is needed, whether explicit modeling of these sources as Archimate elements in an EA model is doubtful but remains unresearched.
- Attributes and value: attributes with their value are already included in many EA modeling tools such as BiZZdesign's Architect. They typically are not explicitly modeled as elements but rather as properties to existing elements. Whether this is sufficient requires further research as important attributes could be paramount to a successful EA. It is expected that providing an option to visualize these along their assets, for example by displaying key attributes in an element, in order to better support decision-making and the modeling of options will be sufficient.

- Decision-making strategy and criteria: While the reasoning behind a decision is important it is unresearched if these can or should be modeled as Archimate components. Like attributes these could be simply the properties of an EA decision.

Chapter 5

Model demonstration

5.1 Preliminary and architecture vision

A fictitious, but realistic, medium-sized insurance company, Archisurance, will be used to realistically illustrate the proposed methodology. Archisurance is the result of a merger of three independent insurance companies: Home & Away, specializing in homeowners- and travel- insurance, PRO-FIT, specializing in car insurance and LegallyYours, specializing in legal expense insurance. All three companies, though offering different products, had similar business models. All three sold insurances directly to consumers and small businesses using a variety of channels such as the web, telephone and mail. During this merger, three years ago, Archisurance implemented TOGAF EAF methods by modeling it through ArchiMate. Its initial objectives had been to ensure business continuity and as a result Archisurance has scattered back-office systems which leads to duplication across the functional structures, roles and capabilities of the organization and causes unnecessary overhead. Recent EA project failures attributed to Archisurance's inability to respond to changes, largely because of this duplication, have increased Archisurance's need to streamline its back-office and directly deal with uncertainty during its development. Archisurance's executives have chosen to implement the FEUD uncertainty-driven decision-making framework, with the goal to establish an agile EA based on their existing TOGAF EA. In their ADM's 'Preliminary Phase', as shown in figure 5.1, they prepare the organization for these new EA activities. Phase A, Architecture Vision, initiates a single architecture development cycle and starts with formulation of a vision of the capabilities and business value to be delivered as part of this project. This motivation can consist of stakeholders, concerns, business requirements, goals, drivers and constraints. It is determined that Archisurance, based on a drive for profit for its shareholders, should set itself a goal to further reduce cost. Executives decide, due to current maintenance and salary costs, that having a single-back office makes a good candidate for further cost-savings. Together with the enterprise architects they start analyzing what requirements are required to reduce cost and gather that such a system broadly should support all financial transactions that currently take place across several systems, support all insurance products and contain a centralized Customer Relationship Management (CRM) system that fully replaces all current ones to avoid duplication and overhead. Two main alternatives are subsequently identified that can potentially reduce cost and at the same time support these requirements:

1. merge the back-office
2. outsource the back-office

Literature points out that the merge alternative can be realized with three broad objectives (Wijnhoven, Spil, Stegwee, & Fa, 2006; McKiernan & Merali, 1995):

1. Absorption

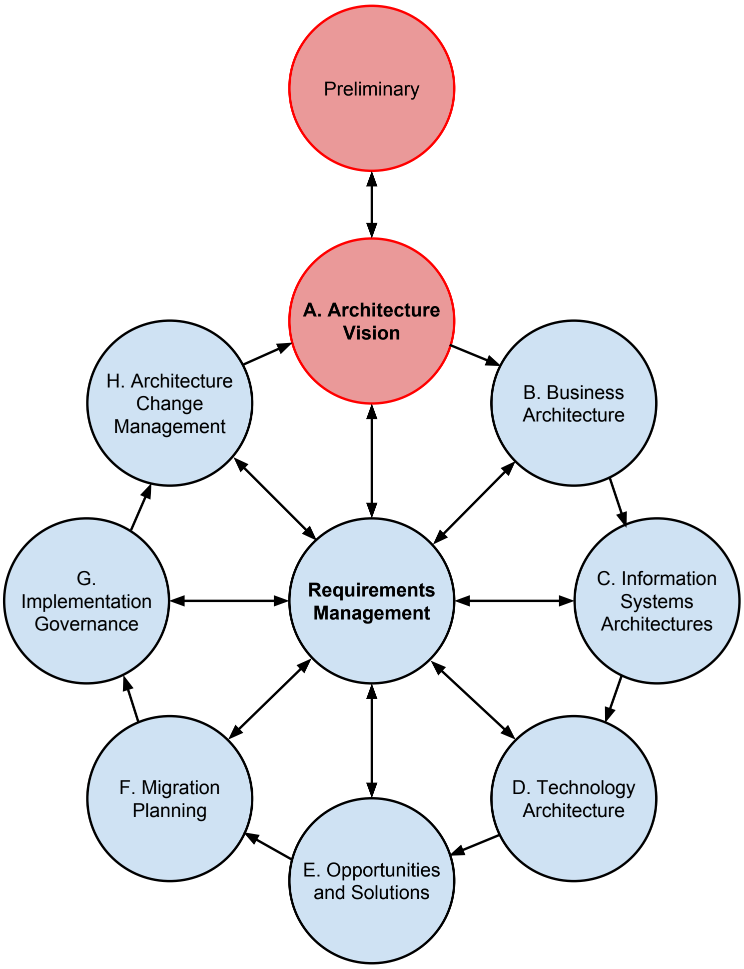


Figure 5.1: TOGAF ADM Preliminary and Architecture vision phase

2. Symbiosis
3. Preservation

In absorption the EA of merged entities are completely integrated to form a new system. A symbiosis selects only the desired aspects of each EA resulting in only partial integration. Preservation maintains existing EAs without integration but synchronizes data in batches. After analysis Archisurance comes up with 3 feasible projects based on the above objectives that will realize a single back-office:

1. Internally develop a new back-office (dubbed the 'development' project)
2. Merge existing back-office systems (the 'merge' project)
3. Outsource back-office services (the 'outsource' project)

5.1.1 Phase 1: Decision investigation

Faced with a decision, the options, shown visually in figures 5.2 to 5.4 are identified, the leaders of Archisurance now proceed to identify uncertainties for each option.

5.1.2 Phase 2: Uncertainty identification

To identify exogenous uncertainties Archisurance has enlisted the aid of a consultant with a history of assisting the insurance industry in risk analysis. The consultant together with

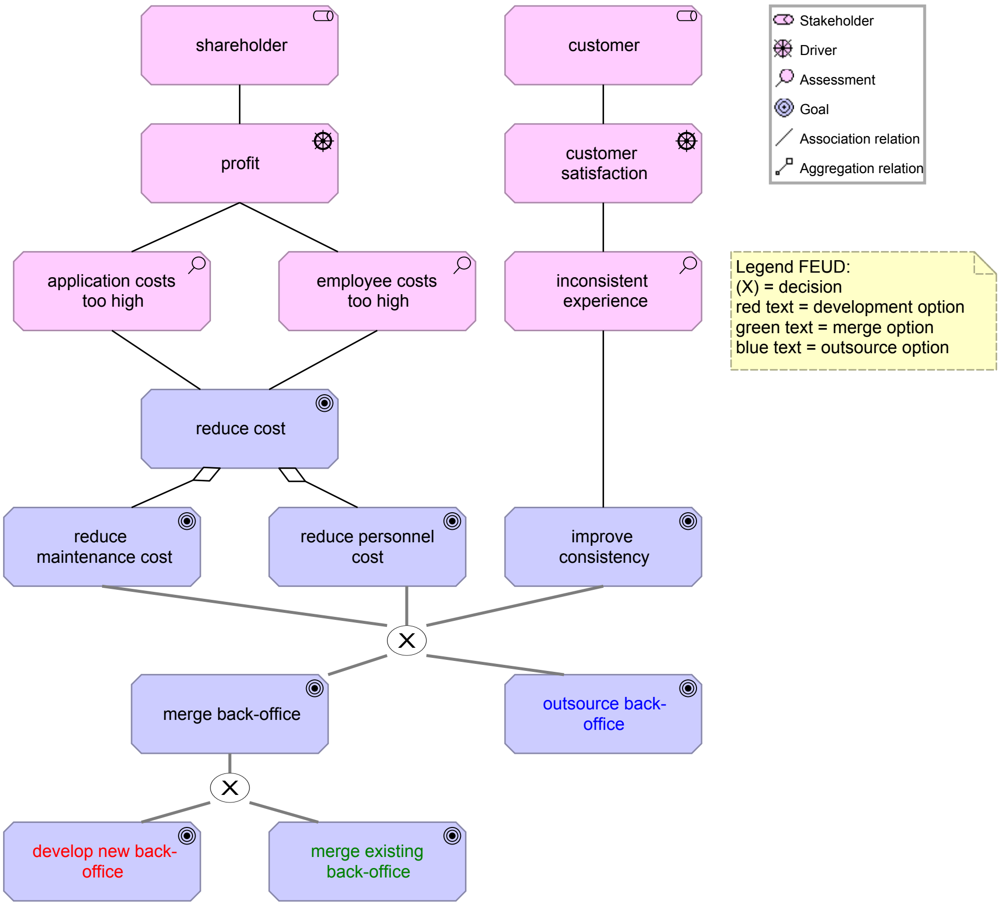


Figure 5.2: Archisurance stakeholder goalview

Archisurance's executives use a PESTLE analysis in order to ensure all exogenous perspectives that are able to cause uncertainty are considered. After the exogenous uncertainty analysis an internal evaluation of capabilities is performed that also includes Archisurance's managers relevant to the development capabilities necessary to complete the single back-office project. The following is a summary of the findings.

Exogenous uncertainties The PESTLE analysis uncovers the following uncertainties in each area relating to the proposed single back-office projects and are summarized in table 5.1.

Political In the domestic market, where the majority of Archisurance's revenue is generated, the announced health-care reforms have lately seen major push-backs and criticism resulting in an initial political rejection of the new health-care plans by the senate and creating instability in and pressure on the governing coalition. Effects from uncertainty about this political instability can be found throughout the health-care industry and it is likely this can have its affect on medical insurances. Financial unrest outside the domestic market is creating political pressure to create and enforce stricter financial legislation and requirements for capital. Archisurance's back-office will need to support this stricter legislation by providing means for increased control and Archisurance will need to oblige to new capital requirements. Political power is seen to globally shift from the western countries (e.g. US & Europe) towards the east (e.g. China & India) and other developing countries (Brazil, Turkey etc.). Stability problems and political ineffectiveness within the European Union can further accelerate this shift and potentially give opportunities to new fast-growing competitors from these regions to enter Archisurance's market.

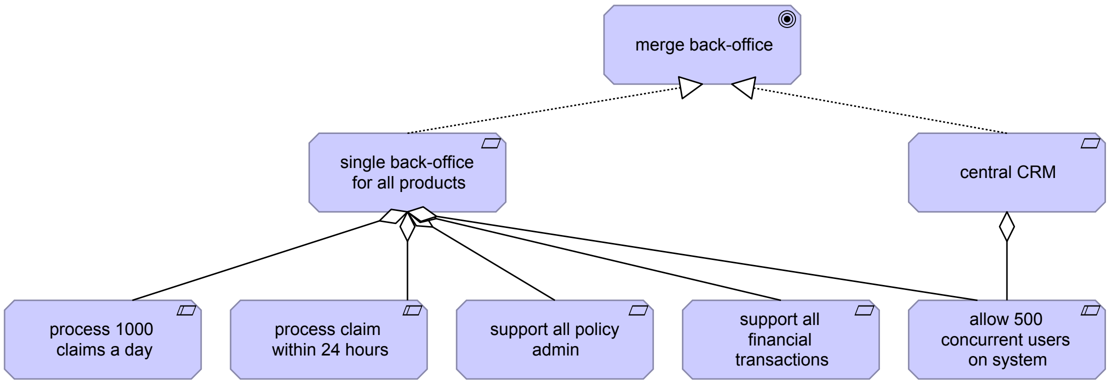


Figure 5.3: Archisurance merge back-office goal realization view

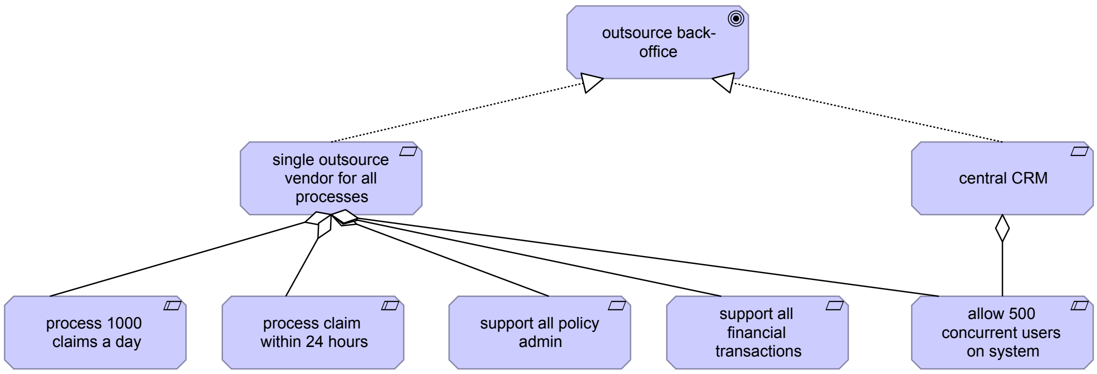


Figure 5.4: Archisurance outsource back-office goal realization view

Economic The economic crisis has affected domestic consumer spending as a result of lower property values, higher retirement premiums, lower benefits, and lower employment and wages. Although there are indications that the economy is set to recover in the coming years, enduring uncertainty persists as above mentioned problems are seen as structural and require further big changes in society and solutions have yet to be put in place, require more time to have their effects assessed and/or involve uncertainty in global economic conditions (i.e. shift of power towards new economies, recovery of the US economy and developments in the Ukrainian conflict to name but a few). For Archisurance this mostly creates an uncertainty in its ability to sell in particular long-term insurance products to its clients, as big purchases, that typically require such insurance, are postponed and clients are seen to seek more flexibility due to their individual uncertain economic conditions. As such this reduces the ability for Archisurance to long-term invest in R&D and is expected to require more flexibility from Archisurance to adapt to changing demands and short-term product trends.

Social Individualization and a rising complexity of society have increased the need for personalized and more flexible insurance products. Archisurance's ability to respond to increased individual needs creates uncertainty in scale, as potentially many customized products will need to be supported, and agility, as its product portfolio will need continuous adjustments to new needs. A single back-office will need to support these changing needs and be able to deal with the associated scope of customization.

Technical Technology increasingly integrates with many aspect of life. The increasing reliance and use also comes with increased risks and an expected increased need for insurance coverage on technical, and possibly even virtual assets (e.g. online persona). Currently its back-office distinguishes the following main types: medical insurance that includes dental insurance, car/vehicle insurance, life insurance, and homeowners' insurance. Extensibility of product offerings is required as well as flexibility to create new insurance types to support new products and create new categories of products. Both privacy and computer security are of great concern as customer insurance records are very privacy sensitive. Centralization of information in one single system can increase potential risks and impact of security flaws. Globalization through technology also exposes Archisurance to new globalized crime which can have both short term economic consequences (e.g. extortion) but also long-term damages to its public image. Currently Archisurance supports claim and account management through a web-portal, however new technologies (e.g. tablet or phone applications) can require different integration. The back-office system will need to support different interfaces to support these.

Legislation Legislation has seen shifts from national to European institutions, this reduces Archisurance's political influence and creates uncertainty as laws can be passed without full consent of the national government. Archisurance, member of an EU insurance organization platform for this very reason, has therefore only limited ability to directly provide European legislators with advice and finds its representation only indirectly through this organization. Legislation changes can lead to non-compliance and fees but also customer attrition if not communicated effectively.

Environmental Changes in our ecology are an increasing cause of concern in our society and the call for change and more sustainable business is seen and recognized by Archisurance as an enduring requirement. Climate change is predicted to cause uncertainty in insurances as weather extremes can affect both local business and damage to property and therefore put pressures on Archisurance insurance products. A bigger potential for catastrophe will require Archisurance to maintain bigger cash reserves and results in limited funds available for more riskful ventures. It also requires the back-office to survive peak usage to ensure availability during such catastrophes.

Endogenous uncertainties Archisurance has made various changes to numerous EA components over the last decade but none involved the scale and scope of the proposed changes in this transition. Not unlike national averages about half the projects for Archisurance were unable to produce desired value and Archisurance's decision makers are worried about their capabilities to turn this project, crucial for the company, into a success. Archisurance identifies the following capabilities important for each of the integration options:

1. development option:
   (a) governance capabilities
       - risk management
       - strategic management
   (b) operational capabilities
       - in-house R&D
       - product innovation
       - product deployment
   (c) organizational capabilities
       - project management
2. merge option:
   (a) governance capabilities
       - risk management

Table 5.1: Archisurance single back-office exogenous uncertainty summary

Area	Uncertainty
political	government instability policy changes financial solvency requirements
economic	profitability investment opportunities take-over susceptibility liquidity requirements
social	individualization product complexity average population age increased medical claims
technical	higher change life cycle adaptability to future technology global exposure privacy concerns security
legislation	EU legislation/constraints claims culture
environmental	sustainability demands low energy consumption climate change climatology/sustainability claims reduced growth 'dirty' industries

- strategic management

(b) operational capabilities

- in-house R&D
- product quality control
- product portfolio management

(c) organizational capabilities

- project management
- asset performance management

3. outsource option (Hirschheim, Heinzl, & Dibbern, 2009):

(a) governance capabilities

- regulatory compliance management
- business planning

(b) operational capabilities

- external R&D
- product acquisition
- product quality control

(c) organizational capabilities
  - project management
  - vendor management
  - sourcing & contract management

Assessing these capabilities the uncertainties in table 5.2 were distilled for each of Archisurance projects.

Table 5.2: Archisurance single back-office endogenous uncertainty summary

Capability	Required for Option	Uncertainty
in-house R&D	development merge	cost estimation time estimation complexity
business planning	outsource	time estimation
product quality control	merge outsource	process performance service quality
asset performance management	merge	service quality
vendor management	outsource	cost estimation time estimation inflexibility

5.1.3 Phase 3: Risk Assessment

Looking at the uncertainties identified in the previous step, Archisurance determines what risks these have on each of the 3 options. An estimation of the impact and likelihood of the risk is made by looking at historic data wherever possible/available and by using experts to create balanced estimations for all measures. First Archisurance decides on the following assessment scales taken from work by Curtis and Carey for Deloitte and COSO (Curtis & Carey, 2012).

Table 5.3: Archisurance risk impact scale based on Curtis and Carey (2012)

Rating	Descriptor	Definition
5	extreme	▪ financial loss of €1 million or more ▪ international long-term negative media coverage; game-changing loss of market share ▪ significant prosecution and fines, litigation including class actions, incarceration of leadership ▪ significant injuries or fatalities to employees or third parties, such as customers or vendors ▪ multiple senior leaders leave
4	major	▪ financial loss of €500 thousand up to €1 million ▪ national long-term negative media coverage; significant loss of market share ▪ report to regulator requiring major project for corrective action ▪ limited in-patient care required for employees or third parties, such as customers or vendors ▪ some senior managers leave, high turnover of experienced staff, not perceived as employer of choice
3	moderate	▪ financial loss of €200 thousand up to €500 thousand ▪ national short-term negative media coverage ▪ report of breach to regulator with immediate correction to be implemented ▪ out-patient medical treatment required for employees or third parties, such as customers or vendors ▪ widespread staff morale problems and high turnover
2	minor	▪ financial loss of €100 thousand up to €200 thousand ▪ national short-term negative media coverage ▪ report of breach to regulator with immediate correction to be implemented ▪ out-patient medical treatment required for employees or third parties, such as customers or vendors ▪ widespread staff morale problems and high turnover
1	incidental	▪ financial loss up to €100 thousand ▪ national short-term negative media coverage ▪ report of breach to regulator with immediate correction to be implemented ▪ out-patient medical treatment required for employees or third parties, such as customers or vendors ▪ widespread staff morale problems and high turnover

Table 5.4: Archisurance risk likelihood scale based on Curtis and Carey (2012)

Rating	Frequency		Probability	
	Descriptor	Definition	Descriptor	Definition
5	frequent	Up to once in 2 years or more	almost certain	90% or greater chance of occurrence over life of asset or project
4	likely	once in 2 years up to once in 25 years	likely	65% up to 90% chance of occurrence over life of asset or project
3	possible	once in 25 years up to once in 50 years	possible	35% up to 65% chance of occurrence over life of asset or project
2	unlikely	once in 50 years up to once in 100 years	unlikely	10% up to 35% chance of occurrence over life of asset or project
1	rare	once in 100 years or less	rare	<10% chance of occurrence over life of asset or project

Table 5.5: Archisurance risk vulnerability scale based on Curtis and Carey (2012)

Rating	Descriptor	Definition
5	very high	▪ No scenario planning performed ▪ lack of enterprise level/process level capabilities to address risks ▪ responses not implemented ▪ no contingency or crisis management plans in place
4	high	▪ scenario planning for key strategic risks performed ▪ low enterprise level/process level capabilities to address risks ▪ responses partially implemented or not achieving control objectives ▪ some contingency or crisis management plans in place
3	medium	▪ stress testing and sensitivity analysis of scenarios performed ▪ medium enterprise level/process level capabilities to address risks ▪ responses implemented and achieving objectives most of the time ▪ most contingency and crisis management plans in place, limited rehearsals
2	low	▪ strategic options defined ▪ medium to high enterprise level/process level capabilities to address risks ▪ responses implemented and achieving objectives except under extreme conditions ▪ contingency and crisis management plans in place, some rehearsals
1	very low	▪ real options deployed to maximize flexibility ▪ high enterprise level/process level capabilities to address risks ▪ redundant response mechanisms in place and regularly tested for critical risks ▪ contingency and crisis management plans in place and rehearsed regularly

Table 5.6: Archisurance risk velocity scale based on Curtis and Carey (2012)

Rating	Descriptor	Definition
5	very high	very rapid onset, little or no warning, instantaneous
4	high	onset occurs in a matter of days to a few weeks
3	medium	onset occurs in a matter of a few months
2	low	onset occurs in a matter of several months
1	very low	very slow onset, occurs over a year or more

Phase 3.1: Risk identification

Archisurance pulls in experts from its ERM division to help identify risks. By using the list of uncertainties identified in section 5.1.2 the risks in tables 5.7 to 5.9 were identified for each uncertainty.

Table 5.7: Archisurance development option risk assessment

Uncertainty	Risk No.	Risk	Risk level	Impact	Likeli-hood	Vulnera-bility	Velocity
cost estimation	d1	cost overrun	16	4	4	3	3
complexity	d2	requirement scope increase	6	3	2	2	2
time estimation	d3	schedule overrun	8	2	4	2	3
process performance	d4	delays	9	3	3	4	3
service quality	d5	customer attrition	6	2	3	4	1
legislation changes	d6	non-compliance	3	1	3	3	3
economic instability	d7	reduced investment	2	2	1	4	2
scalability	d8	low performance	6	2	3	3	4
security	d9	trust lost	6	3	2	3	2
security	d10	privacy breach	8	4	2	2	4

Table 5.8: Archisurance merge option risk assessment

Uncertainty	Risk No.	Risk	Risk level	Impact	Likeli-hood	Vulnera-bility	Velocity
cost estimation	m1	cost overrun	16	4	4	3	3
complexity	m2	business continuity interruption	6	3	2	2	2
time estimation	m3	schedule overrun	8	2	4	2	3
process performance	m4	delays	9	3	3	4	3
legislation changes	m5	non-compliance	3	1	3	3	3
economic instability	m6	reduced investment	2	2	1	4	2
scalability	m7	low performance	6	2	3	3	4
security	m8	trust lost	6	3	2	3	2
security	m9	privacy breach	8	4	2	2	4

Table 5.9: Archisurance outsource option risk assessment

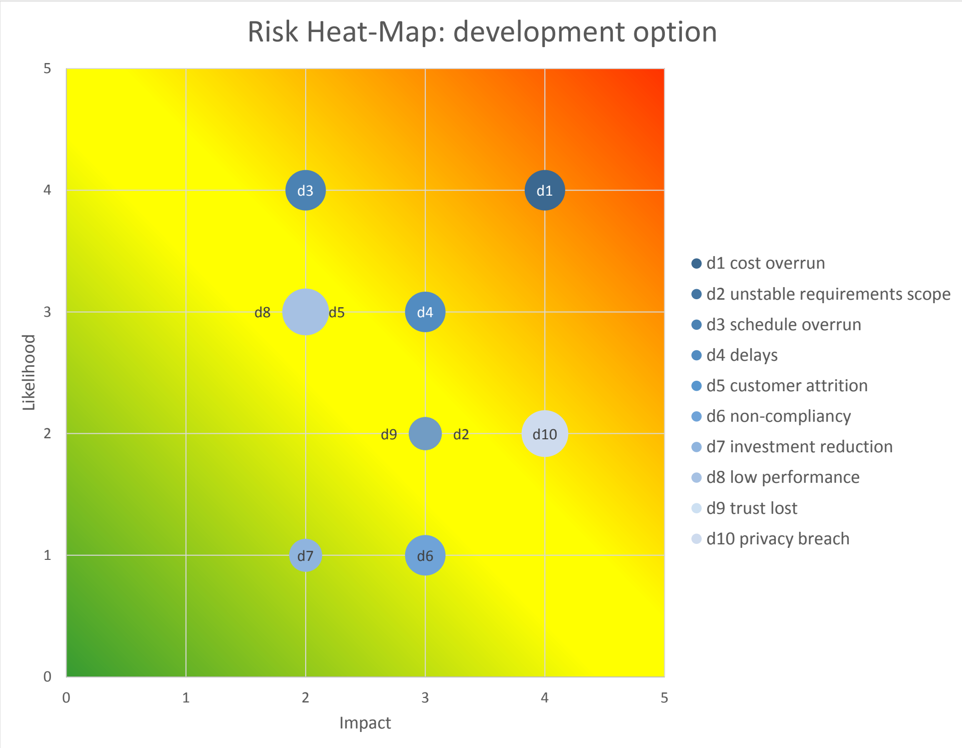
Uncertainty	Risk No.	Risk	Risk level	Impact	Likeli-hood	Vulnera-bility	Velocity
time estimation	o1	schedule overrun	8	2	4	2	3
process performance	o2	delays	9	3	3	4	3
inflexibility	o3	vendor lock-in	3	1	3	3	3
legislation changes	o4	non-compliance	2	2	1	4	2
economic instability	o5	reduced investment	6	2	3	3	4
security	o6	trust lost	6	3	2	3	2
security	o7	privacy breach	8	4	2	2	4

Phase 3.2: Risk analysis

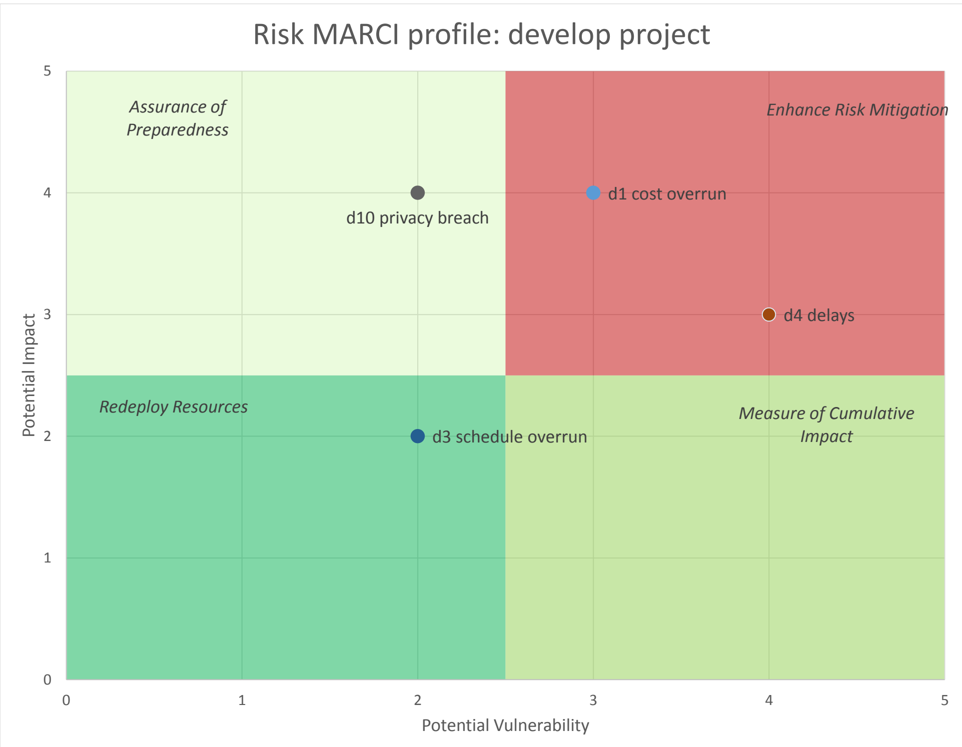
Archisurance uses the previously established assessment scales to assess the risks for each project. The estimation of the impact, likelihood, vulnerability and velocity of each risk is made by looking at historic data wherever possible/available and by interviewing multiple experts to create balanced estimations for all measures.

Phase 3.3: Risk evaluation

To focus on the key risks Archisurance draws the following heat-maps and MARCI charts, choosing to focus only on the risks in the 'red' area with a risk-level (product of impact and likelihood) greater than eight. These 'key-risks' are subsequently plotted on a MARCI risk profile chart to identify those risks that would benefit from additional risk-mitigation. As mentioned in section 3.7.1 risks in the other quadrants also require additional attention, this is outside the scope of this case example.

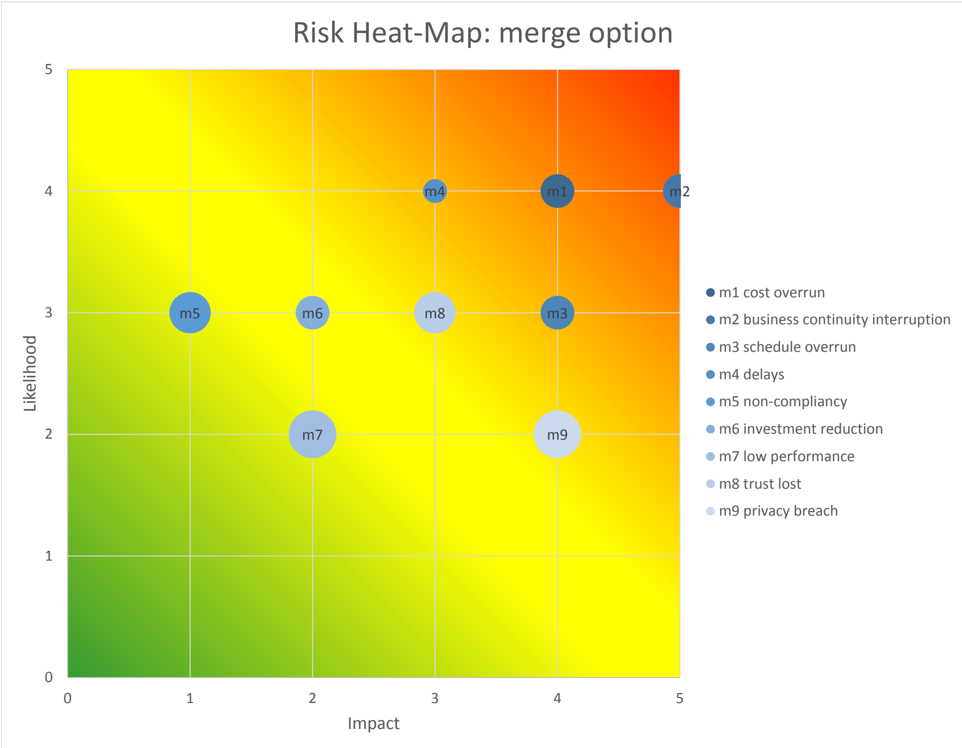


(a) Archisurance development option risk heat-map

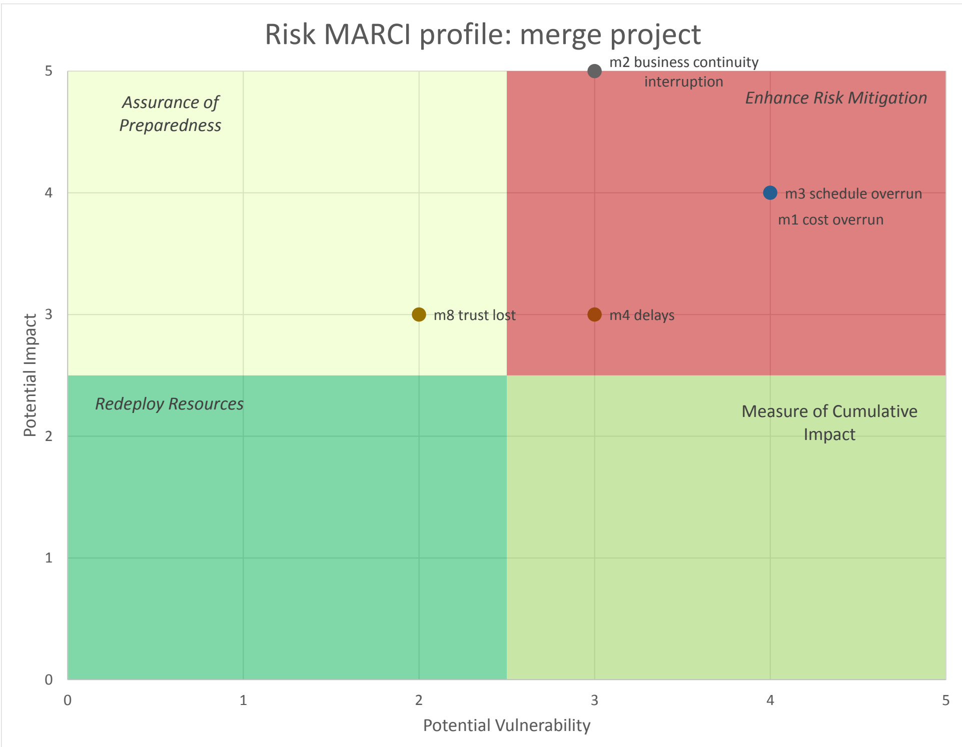


(b) Archisurance development option MARCI chart

Figure 5.5: Archisurance development option risk assessment

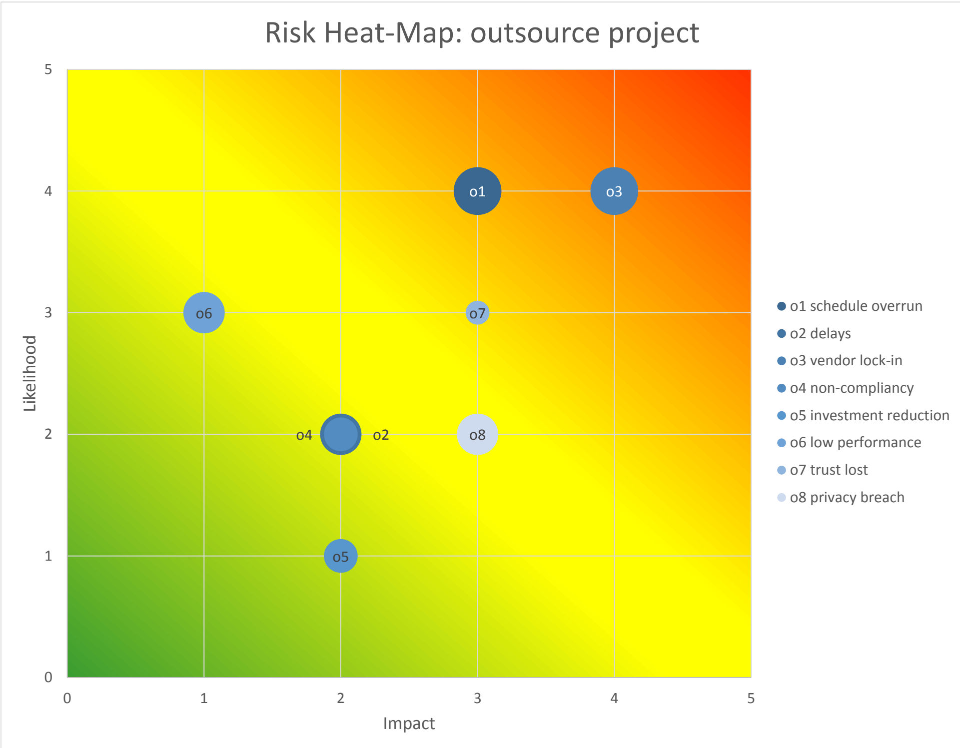


(a) Archisurance merge option risk heat-map

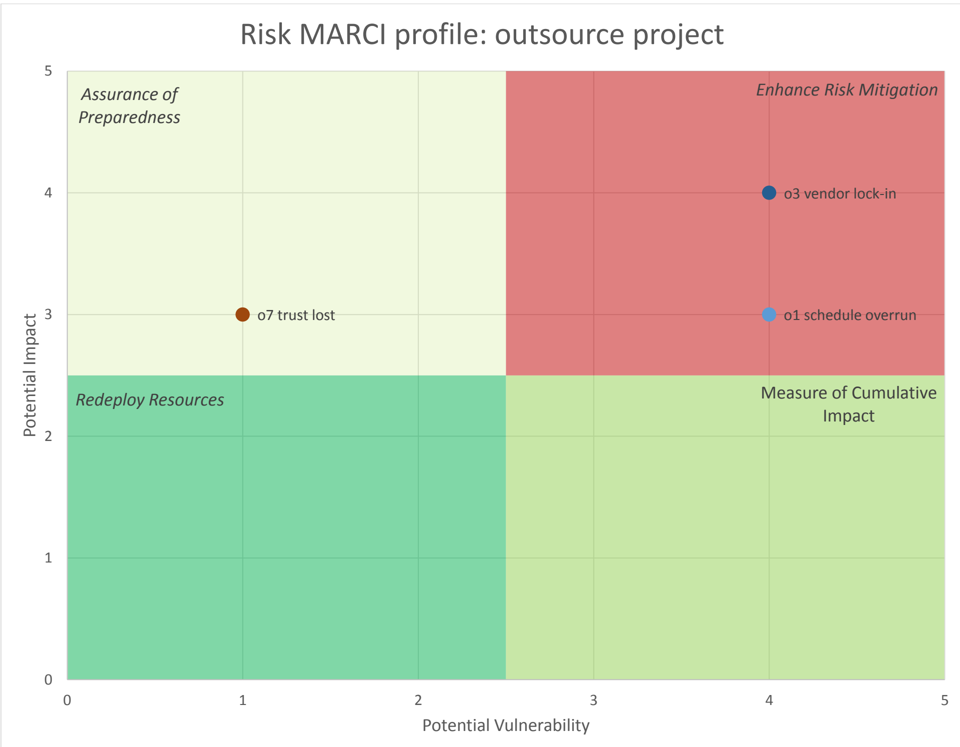


(b) Archisurance merge option MARCI chart

Figure 5.6: Archisurance merge option risk assessment



(a) Archisurance outsource option risk heat-map



(b) Archisurance outsource option MARCI chart

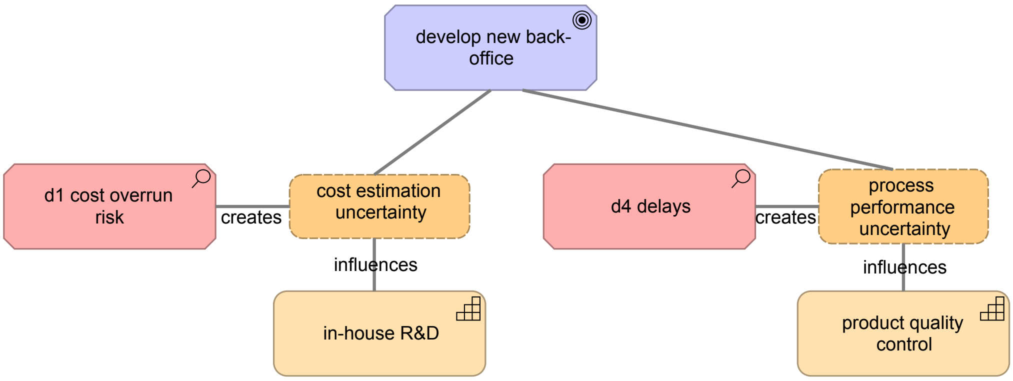
Figure 5.7: Archisurance outsource option risk assessment

The key-risks, summarized in table 5.10, can subsequently be added to the Archimate archi-

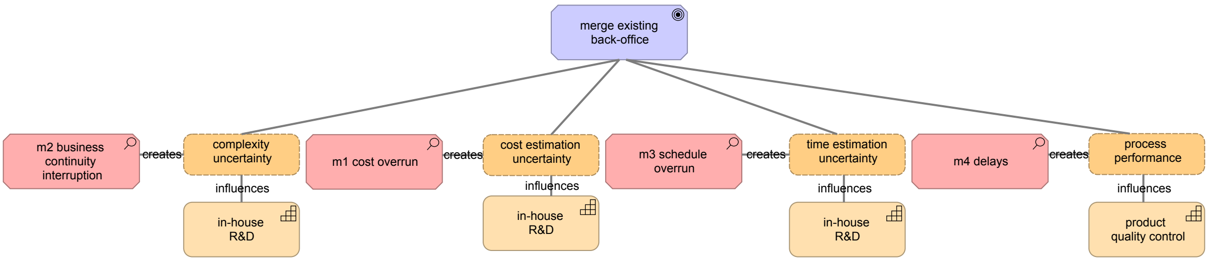
Table 5.10: Archisurance key-risks summary

Option	Risk No.	Risk
development	d1	cost overrun
development	d4	delays
merge	m1	cost overrun
merge	m2	business continuity interruption
merge	m3	schedule overrun
merge	m4	delays
outsource	o1	schedule overrun
outsource	o3	vendor lock-in

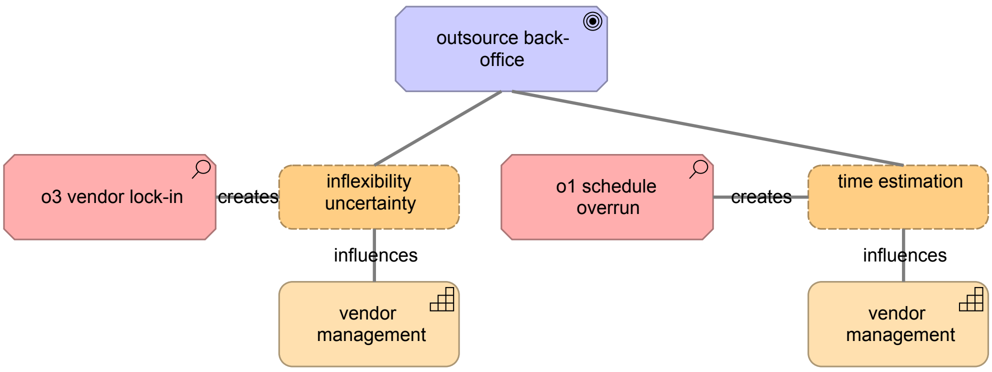
tecture description as seen in figure 5.8.



(a) Archisurance development option uncertainty and risk



(b) Archisurance merge option uncertainty and risk



(c) Archisurance outsource option uncertainty and risk

Figure 5.8: Archisurance Uncertainty identification and Risk assessment

5.1.4 Phase 4: Risk treatment design

Archisurance uses the MARCI charts created in the previous step to select the key risks that require treatment. The architects, at a strategic level, look at the risks, sorted by their risk level in table 5.11, to identify and design suitable real options that have the potential to mitigate the risks.

Table 5.11: Archisurance key-risks hedging options

Option	Risk No.	Risk	Risk level	Real Option	
				Mechanism	Flexibility
development	d1	cost overrun	16	invest in strategy evaluation opportunity at cost of €10000	abandon project after 1 year to salvage €50000
development	d4	delays	9	invest in strategy modularization at a cost €10000	contract project scope by 12% each year to save €50000
development	d4	delays	9	invest in strategy modularization at a cost €10000	extend project scope by 20% each year at additional cost of €10000
merge	m2	business continuity interruption	20	invest in ability to keep old back-office at a cost €10000	defer project by 2 years when intrinsic cash flow is lower as initial costs €80000
merge	m1	cost overrun	16	invest in strategy evaluation ability at cost €10000	abandon project after 1 year to salvage €50000 in value
merge	m3	schedule overrun	12	invest in strategy modularization at a cost €40000	contract project scope by 25% each year to save €40000
merge	m4	delays	12	invest in strategy modularization at a cost €40000	contract project scope by 25% each year to save €40000
outsource	o3	vendor lock-in	16	invest in contract termination at a cost €30000	abandon project after 1 year to salvage €87000 in value
outsource	o1	schedule overrun	12	invest in late-delivery fees on contracts at a cost €40000	increase value by claiming fee €50000 when value drops below 50%

5.1.5 Phase 5: Option valuation

Archisurance constructs a DCF for each of the options. Each DCF includes a discount rate, because all projects face the same exogenous risks it can be calculated once for all three projects. The effects of exogenous risks are calculated through a WACC calculation, see section 3.2.1, using the CAPM to describe the relationship between risk and expected returns:

$$
\begin{aligned}
WACC &= rD * (1 - Tc) * (\frac{D}{V}) + rE * (\frac{E}{V}) \\
&= 3.43\% * (\frac{€61.70}{€185.33}) + 17.78\% * (\frac{€123.63}{€185.33}) = 13\% \\
\text{where} & \\
rD * (1 - Tc) &= \text{cost of debt after tax} = 3.43\% \\
\text{where } rD &= \text{cost of debt} = 5.36\% \\
Tc &= \text{corporate tax rate} = 36\% \\
\text{and} & \\
\frac{D}{V} &= \text{proportion of debt} = 0.33 \\
\text{where } D &= \text{total debt} = \text{book value} * \text{adjustment} = €61.70 \\
\text{book value} &= €61.70 \\
\text{adjustment} &= 1 \\
V &= \text{total value} = E + D = €185.33 \\
\text{and} & \\
rE &= \text{cost of equity} = rf + \beta(rM - rf) \\
\text{where } rf &= \text{risk free rate} = 0.30\% \\
\beta &= \text{predicted beta} = 2 \\
rM &= \text{market return} = 9.04\% \\
\text{and} & \\
\frac{E}{V} &= \text{proportion of equity} = 0.67 \\
\text{where } E &= \text{value of equity} = \text{shares} * \text{price} = €123.63 \\
\text{shares} &= 0.951 \\
\text{price} &= €130
\end{aligned}
$$

Development option

The development project is expected to ultimately generate the most cost savings but initially requires large investments (CAPEX). The following DCF shows a five year forecast for the development project and rates the project with a NPV of $€76,693.97$, see table 5.12. By running a Monte-Carlo simulation using an estimated volatility (σ) of 0.05 on both the variable cost decrease rate of 15% and the revenue increase of 25% (normally distributed) Archisurance estimates the net present value of the Development Option to be $€77,875.10$.

Table 5.12: Archisurance Development Option Cash Flow Forecast

Year	2015	2016	2017	2018	2019	2020
Period	0	1	2	3	4	5
CAPEX	50.00					
Variable cost decrease (%)		15.00	15.00	15.00	15.00	15.00
Variable cost rate (€100K)		42.50	36.13	30.71	26.10	22.19
Fixed costs (€100K)		50.00	50.00	50.00	50.00	50.00
Total costs (€100K)		92.50	86.13	80.71	76.10	72.19
Revenue increase (%)		25.00	25.00	25.00	25.00	25.00
Revenue (€100K)		62.50	78.13	97.66	122.07	152.59
Cash flow (€100K)		(30.00)	(8.00)	(16.95)	(45.97)	(80.40)
Discounted CF (€100K)		(26.55)	(6.27)	11.75	28.19	43.64
Present value of CF (€100K)	50.77	57.37	98.72	120.60	117.12	80.40
CF payout rate (€100K)		(1.91)	(12.34)	7.11	2.55	1.00
Discount rate (%)	13.00					
Net present value (€100K)	0.7669					
Internal rate of return (%)	13.27					

With the estimated cash flows the logarithmic present value approach shown in table A.1 of appendix A can be used to calculate a return ratio of 0.1222 that can be monitored in a Monte Carlo simulation to obtain a standard deviation of 0.5881. Using the σ of 0.5881 the binomial up and down movement and probability parameters are obtained:

$$u = e^{\sigma\sqrt{t}} = e^{0.5881\sqrt{1}} = 1.8005$$
$$d = e^{-\sigma\sqrt{t}} = \frac{1}{u} = 0.5554$$
$$p = \frac{e^{(r-q)t} - d}{u-d} = \frac{e^{(13\%-0)1} - 0.5554}{1.8005 - 0.5554} = 0.4686$$

With these parameters the binomial lattice and decision lattice for the development option are constructed as shown in appendix A tables A.2 and A.3.

Merge option

The merge option has lower initial investment costs but also lower cost savings and an ultimately lower revenue forecast. The NPV is forecasted at only €$1,958.22$ after 5 years. By running a Monte-Carlo simulation using an estimated volatility (σ) of 0.03 on both the variable cost decrease rate of 12% and the revenue increase of 22% (normally distributed) Archisurance estimates the net present value of the Merge Option to be €$2,239.94$. With the estimated

Table 5.13: Archisurance Merge Option Cash Flow Forecast

Year	2015	2016	2017	2018	2019	2020
Period	0	1	2	3	4	5
CAPEX	15.00					
Variable cost decrease (%)		12.00	12.00	12.00	12.00	12.00
Variable cost rate (€100K)		44.50	38.72	34.07	29.98	26.39
Fixed costs (€100K)		50.00	50.00	50.00	50.00	50.00
Total costs (€100K)		94.00	88.72	84.07	79.98	76.39
Revenue increase (%)		22.00	22.00	22.00	22.00	22.00
Revenue (€100K)		61.00	74.42	90.79	110.77	135.14
Cash flow (€100K)		(33.00)	(14.30)	6.72	30.78	58.75
Discounted CF (€100K)		(29.20)	(11.20)	4.66	18.88	31.89
Present value of CF (€100K)	15.02	16.97	56.47	79.97	82.77	58.75
CF payout rate (€100K)		(0.51)	(3.95)	11.90	2.69	1.00
Discount rate (%)	13.00					
Net present value (€100K)	0.0196					
Internal rate of return (%)	13.01					

cash flows the logarithmic present value approach shown in table A.4 of appendix A can be used to calculate a return ratio of 0.1222 that can be monitored in a Monte Carlo simulation to obtain a standard deviation of 0.4324. Using a σ of 0.4324 the binomial up and down movement and probability parameters are obtained for the merge project:

$$
\begin{aligned}
u &= e^{\sigma\sqrt{t}} = e^{0.4324\sqrt{1}} = 1.5409 \\
d &= e^{-\sigma\sqrt{t}} = \frac{1}{u} = 0.6490 \\
p &= \frac{e^{(r-q)t} - d}{u-d} = \frac{e^{(13\%-0)1} - 0.5409}{1.5409 - 0.6490} = 0.5492
\end{aligned}
$$

With these parameters the binomial lattice and decision lattice for the development option are constructed as shown in appendix A tables A.5 and A.6.

Outsource option

The outsource option has both the lowest initial cost and variable cost, a higher fixed cost of outsourcing and lower revenue increase impact. It's base NPV is estimated at €206,738.66. Risks are considered relatively low and a volatility σ of 0.01 is put on both the variable cost decrease of 8% and revenue increase of 20%. The risk adjusted NPV is estimated through Monte Carlo simulation at €$206,685.39$. With the estimated cash flows the logarithmic present value approach shown in table A.7 of appendix A can be used to calculate a return ratio of 0.1222 that can be monitored in a Monte Carlo simulation to obtain a standard deviation of 0.3772. Using a σ of 0.3772 the binomial up and down movement and probability parameters

Table 5.14: Archisurance Outsource Option Cash Flow Forecast

Year	2015	2016	2017	2018	2019	2020
Period	0	1	2	3	4	5
CAPEX	10.00					
Variable cost decrease (%)		8.00	8.00	8.00	8.00	8.00
Variable cost rate (€100K)		13.80	12.70	11.68	10.75	9.89
Fixed costs (€100K)		70.00	70.00	70.00	70.00	70.00
Total costs (€100K)		83.80	82.70	81.68	80.75	79.89
Revenue increase (%)		20.00	20.00	20.00	20.00	20.00
Revenue (€100K)		60.00	72.00	86.40	103.68	124.42
Cash flow (€100K)		(23.80)	(10.70)	4.72	22.93	44.53
Discounted CF (€100K)		(21.06)	(8.38)	3.27	14.07	24.17
Present value of CF (€100K)	12.07	13.64	42.30	59.89	62.34	44.53
CF payout rate (€100K)		(0.57)	(3.96)	12.69	2.72	1.00
Discount rate (%)	13.00					
Net present value (€100K)	2.0674					
Internal rate of return (%)	14.64					

are obtained for the merge project:

$$
\begin{aligned}
u &= e^{\sigma\sqrt{t}} = e^{0.3772\sqrt{1}} = 1.4582 \\
d &= e^{-\sigma\sqrt{t}} = \frac{1}{u} = 0.6858 \\
p &= \frac{e^{(r-q)t} - d}{u - d} = \frac{e^{(13\%-0)1} - 0.6858}{1.4582 - 0.6858} = 0.5865
\end{aligned}
$$

With these parameters the binomial lattice and decision lattice for the development option are constructed as shown in appendix A tables A.8 and A.9.

5.1.6 Phase 6: Decision making

Archisurance compares the three projects based on the expected values after selecting the risk treatments that maximize value. Table 5.15 shows the options in an overview with their basic NPV (without flexibility), extended NPVs for each flexibility and the maximum extended NPV where only positive real options are included. From this calculation the "development" project comes out the most valuable due to its very high flexibility. If the only criteria concerned is the expected value the Archisurance executives, if in agreement with the various assumptions made throughout this option valuation, would choose to implement the development project and invest in both the scope-down and scope-up option, but not in the abandonment option, with the expectation of earning €256446.67 over 5 years at a 13% discount rate.

5.1.7 Phase n: continued

Note that the above cycle only represents the first iteration with initial estimates. It provides a first comparison of the different options and is intended to facilitate more discussion between executives, enterprise architects and the finance department of Archisurance. Subsequent iterations will validate and improve the estimations, as well as likely discovery of other options and involve additional stakeholders from Archisurance. This cycle also only discusses the three options from a strategic level, once the strategic levels have been worked out in more detail and with enough confidence to make a decision on an option, the TOGAF ADM cycle will continue to the business phase and is likely to substantiate on many of the estimations, giving more concrete investment figures to allow better value estimates. It is possible that several options are pursued in order to reach the confidence of a final decision. The real options,

Table 5.15: Archisurance Decision Making

Option	Value	Option Cost	Flexibility value
Development option			
NPV basic	76693.97		
NPV w. abandon	85269.24	10000	-1424.73
NPV w. scope-down	211893.01	10000	125199.04
NPV w. scope-up	155624.12	10000	68930.15
NPVe max	256446.67	20000	159752.7
Merge option			
NPV w. basic	1958.22		
NPV w. defer	80000	10000	68041.78
NPV w. scope-down	60769.09	40000	18810.87
NPVe max	89855.56	50000	75794.68
Outsource option			
NPV w. basic	206738.66		
NPV w. abandon	208257.52	30000	-28481.14
NPV w. scope-up	245945.91	30000	9207.24
NPVe max	245945.91	30000	9207.24

representing an investment mechanism to enable future flexibilities, chosen in the strategic dimension will form additional requirements in the design of related business, application and technology architectures. Archisurance EA model will require the business, application and technology layers to provide scalability, both up and downward, to successfully implement the scope-up and scope-down real options desired in the development option. Archisurance's executives think they can achieve this by hiring new personnel on this project with temporary contracts and by relocating cross-functional employees internally to achieve such flexibility in the business layers. The new business processes can be extended to all three Archisurance departments or just one or two, this requires a phased roll-out and a process that can operate besides currently existing processes. The new back-office application is to be designed such that extending its products to these other departments can be performed without architectural changes, this requires a data-model with opportunities for extension as well as more flexible system architecture through service orientation. After discussions with the IT department it is also chosen to target the new back-office to a cloud infrastructure as it enables infrastructure virtualization that provides a very flexible pay-as you go service without up-front investments. Figure 5.9 shows an example how Archisurance can continue modeling EA in the business architecture phase that takes the uncertainties, risks and flexibilities identified earlier into account.

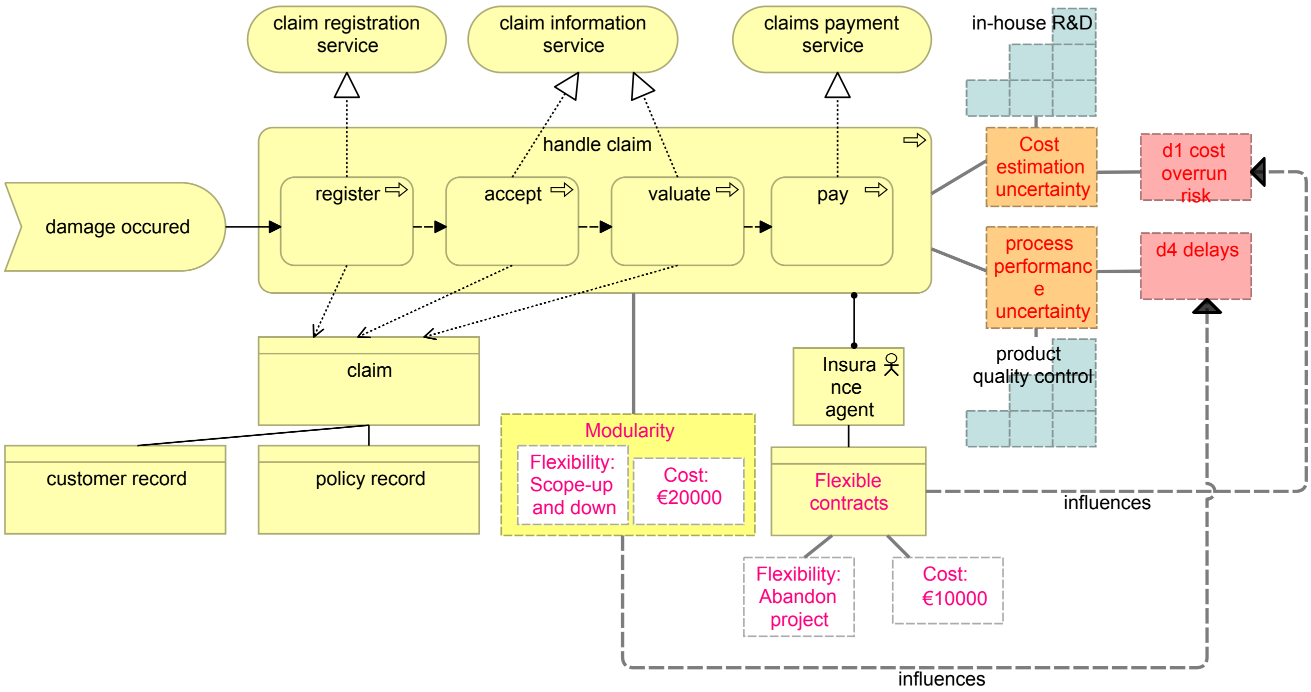


Figure 5.9: Archisurance develop back-office business process view

Chapter 6

Evaluation

The Design Science Research Methodology, as discussed in chapter 2, requires an evaluation that verifies the functioning of the artifact against the earlier set research objectives. This evaluation can use both quantitative as well as qualitative techniques depending on the nature of research problems and the proposed artifact (Peffers et al., 2007). Evaluation took place in an iterative process where, in particular during the artifact demonstration, identified problems were processed and solved before continuing further evaluation. Multiple methods were leveraged to study the interaction between the artifact, the FEUD framework, and its context, decision-making that deals with uncertainty in an enterprise architecture. To provide both a wide and thorough evaluation we first proposed the framework to several field experts to yield in-depth feedback. After processing the feed-back an expert-panel presentation was given to a broader audience, that included both academic and industry experts from multiple companies, that provided the opportunity for a direct assessment of opinions. Ultimately a survey was conducted by providing both a printed and online questionnaire to the same broad group that allowed the sampling of anonymous and individual responses.

6.1 Expert meetings

To obtain a thorough understanding of the effects of the artifact several meetings were conducted with experts to gather their feedback. Their input was recorded, registered and summarized in minutes and sent for review to all participants. The initial group, consisting out of the thesis supervisors, included academic expertise on enterprise architecture with both a technical-, i.e. computer science, as well as a business-, i.e. business administration, background as detailed in section 2.2. Due to integration of financial valuation methods an additional expert was approached from the the Computational Finance faculty that provided additional evaluation on financial aspects.

6.2 Focus group

A focus group session was organized to evaluate the scientific foundation of the framework across a group of experts. Saunders, Lewis, and Thornhill (2012) define a focus group as a "group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research". The subject, the concepts introduced in this research, therefore is set by the researcher and provide the focus of the groups interaction. A focus group serves to receive feedback on a range of concepts and also to highlight variations in perspectives between participants (Kitzinger, 1994). The interaction, in this case the discussions between the individual experts, therefore was encouraged by the researcher and serves to build bridges between different perspectives and can create a shared understanding. As stated by Saunders et al. (2012) in a focus group its "participants are normally chosen using non-probability sampling, often with a specific purpose in mind". A focus group was chosen for this research as it provides a well established qualitative method of data collection on a specific topic with a practitioner's point of view. It gives opportunity to gather a rich description and analysis of the subject's phenomenon in context and therefore assists in evaluating industry relevance.

For this research a focus group was assembled with practitioners from BiZZdesign, InnoValor and the University of Twente. As mentioned in section 2.2 BiZZdesign is an industry leading company that has an academic and corporate background in enterprise architecture related products and services and is a key founder of Archimate. This research included two BiZZdesign enterprise architecture experts that had specific backgrounds in risk management, strategic planning, capability management and value design. InnoValor is a Dutch consultancy with an academic history as a research institute that provides organizations with advice on digital opportunities such as digital trust, business models and agility. Two Innovalor consultants brought specific knowledge and experience on strategic management, business/investment valuation and information security. Three University of Twente focus group participants were academics from the faculty of behavioural, management and social sciences (BMS) or the faculty of electrical engineering, mathematics and computer science (EEMCS) which includes expertise on business information systems, information and software systems engineering (ISSE) and services, cybersecurity and safety (SCS). A total of seven participants forms an ideal group size, supported by research (Onwuegbuzie, Dickinson, Leech, & Zoran, 2009), for discussions as it encourages all participants to participate yet typically yields enough diversity in the information provided.

The focus group session kicked-off with a 45-minute presentation that introduced the framework, explained the theory and demonstrated the framework through simplified example. This helped communicate the objectives, provide initial definitions for key concepts and sets the focus on desired topics in the discussion to follow. Both the presentation as well as the discussions were recorded (audio-only) with consent of the participants and notes were taken to capture non-verbal data. This allows for in-depth post-session analysis that captures the entire discussion without risk of missing information. Discussion took around an hour and covered various topics summarized in the following.

6.2.1 Roles

Much discussion evolved around the roles that are involved in and can make use of the framework. As the framework presents itself as a bridge between executive, finance and enterprise architects much debate evolved around which roles would typically be involved in which part of the decision-making cycle. It was suggested that certain phases, namely the risk assessment and treatment phases would require specialized personnel, in particular with more risk-management and financial backgrounds. Some also argued that although executives are ultimately responsible it is likely they will often delegate decision making to employees reporting to them. This was countered by others by expressing that decision-making ought to be an executives primary function. It was agreed upon that regardless it was worth having a structured process around decision-making.

6.2.2 Complexity

Another topic that predominantly centered around the valuation computations involved the complexity of the framework. Some practitioners had questions around the feasibility to implement this framework in complex business environments. Principally the amount of time required to investigate the uncertainties, distill the risks and represent them in the discounted cash flow valuations were considered and expected to be costly. The FEUD framework tries to mitigate this by prioritizing and filtering the risks, for example through the HEAT and MARCI charts as performed in chapter 4, in order to only focus on risks to which the enterprise has a high expected vulnerability. Practitioners agreed that although real option theory remains complex, the decision-making framework was straightforward and there was little room to further simplify considering the complexity of business decisions in general. The actual real option valuation, if considered practical across an EA, was viewed by participants as a black-box "application". Roles without financial and computational background are then expected to still be able to leverage it for their risk mitigation. It was deemed crucial to have a clear identification of any assumptions made, in particular where it pertains to risks or cash flow estimates. Currently these estimates were included by FEUD in the Archimate model as attributes of elements such as risks. It is suggested a sensitivity analysis, not covered in this research, can further help to prioritize risks. This also suggests, as expected, human judgment to remain paramount in business decision-making as it can reduce complexity by filtering those decisions that are likely to benefit from this framework's structure. Although it is expected that those decisions that involve big investments and deal with large uncertainty to benefit the most this has not been measured in this research.

6.2.3 Positive risk

As detailed in section 3.7 risk can include both negative and positive events. Negative risks are often called threats while positive risks are opportunities. Positive risks, i.e. opportunities, are implicitly dealt with in the FEUD framework, in fact no differentiation is made between negative or positive risk and real option theory can provide valuable valuation on flexibilities that supports opportunities such as scale-up options. The risk-treatments suggested in FEUD, i.e. avoidance, reduction, sharing, and retention, indicate a focus on negative risks which is unintended.

6.2.4 Usage

Discussion persisted on the scope of application the framework would have along with questions on the current fields of application of real options theory. Real options have seen wide application in strategic investments evaluation in the oil & gas industry (Fernandes, Cunha, & Ferreira, 2011), on infrastructure investments (such as in water management) (Garvin & Ford, 2012) and with product development in the pharmaceutical industry (Gunther McGrath & Nerkar, 2004). Recently real option valuation has found new application in such areas as valuing motion picture investments in the film industry (Gong, Van der Stede, & Mark Young, 2011), security investments (Franqueira et al., 2010), supply chain management (Cucchiella & Gastaldi, 2006), and in e-learning investments (Freitas & Brandão, 2010). It was considered likely that in these areas integration of real option valuation techniques in a enterprise architecture context would find quick adoption. This led to questions on what industries have not explored real option valuation and more importantly why. It was deemed interesting to investigate if an integrated framework could provide new incentive for applications in these industries.

6.3 Questionnaire

The questionnaire is aimed to evaluate the framework by verifying it meets the research objectives stated earlier in section 2.3 and provides for triangular sourced conclusions (i.e. by cross-checking findings in the expert opinions, focus-groups, and now the questionnaire). Babbie (2010) defines a questionnaire "an instrument specifically designed to elicit information that will be useful for analysis". In order to perform this analysis successful, i.e. such that it shows if objectives have been met, it is crucial the right information is elicited correctly. While the focus group was more exploratory by design, "revealing dimensions of understanding that often remain untapped by the more conventional one-to-one interview or questionnaire" (Kitzinger, 1994) the questionnaire gives feedback on specific topics. Powell and Single (1996) states a valid questionnaire can be constructed or enhanced by the knowledge generated in the focus group and therefore can be used complementary (McLeod, Meagher, Steinert, & Boudreau, 2000; Barbour, 2005). A valid questionnaire is an efficient method to to gather responses on the same predetermined questions, this makes it suitable as measurement tool used for further data analysis in particular through software with statistical functions (i.e. Microsoft Excel or IBM SPSS). A self-administered questionnaire was developed and distributed both in paper and online format. While (in particular online) self-administration generally requires little resources, it notoriously suffers from a lower response compared to those administered by interviews and is prone to suffer from "uninformed response" (Saunders et al., 2012).

6.3.1 Questionnaire design

A semi-structured questionnaire is designed and sectioned in the following distinct parts:

1. Introduction. An introduction to the framework was provided in a presentation that explained the concepts using a real-world example. The questionnaire included diagrams and a list of concept definitions to ensure respondents were sufficiently informed.

2. Personal. Data on the respondent is gathered. This includes the date the questionnaire (automatically tagged in the online version) was filled out, an optional name (to allow anonymous response) and information on the respondent's occupation.

3. Definitions and concept. Scalar questions are used to determine the clarity of selected definitions and usefulness of concepts on a 5-point Likert scale. These were deliberately easy questions that allow the respondent to gain confidence and should help respondents make more informed responses in the questions to follow.

4. FEUD. Information was gathered on the usefulness of FEUD in relation to key concepts such as decision-making and agility.

5. Practitioners. This section attempts to elicit understanding on the practicality of the framework for the industry.

6. Real Option Valuation. Respondents can give their opinion on ROV with a specific focus on the method's complexity.

7. Decision-making. The usefulness of documenting decisions and options in Archimate is tested was of interest.

8. Verbatim response. The questionnaire includes a section that provides an open-question in order to allow respondents to give any additional information missed in earlier sections or provide comments on the survey itself.

The questionnaire was developed by making use of "google forms", an online product by Google Inc. that supports the creation and easy distribution of questionnaires online. Google forms can print the same questionnaire for easy offline usage which ensures consistency. Responses from the online form were extracted to a spreadsheet, and appended with the offline responses, which greatly simplifies statistical analysis as demonstrated in the next section. To ensure validity the questionnaire was initially verified by the research supervisors who approved both its format and the relevance of the questions. A full example of the questionnaire can be found in appendix B. Further testing ensued by performing a pre-test in which two respondents filled out the questionnaire prior to its distribution and the results, with a particular focus on the clarity of the (introduced) concepts, were discussed and reflected. Any indicated confusion was then resolved by adjusting the questionnaire accordingly. Due to time constraints of this research the respondent group was sourced in the participants of the focus group and totaled seven fully filled out questionnaires. Therefore, while the questionnaire forms a good base for further research its results can only be considered an indication that aims to verify specific topics of the focus group findings. As such it requires further empirical research as described by Saunders et al. (2012), Babbie (2010) on a larger population sample to draw further and statistically more relevant conclusions.

6.3.2 Data analysis

After all response data became available in a spreadsheet the first step was to scan and analyze the raw data for errors or anomalies. Because the design of the online response form included various constraints not many problems were discovered. An offline response however, made by a person that subsequently also filled out the online questionnaire, was filtered and successfully removed from the results to avoid duplication. The next sections follow the structure of the questionnaire as detailed above.

Personal

The questionnaire was filled out by respondents with a position of a consultant, researcher or student as shown in figure 6.1. Not shown is that some of the respondents that identified as student, researcher or consultant did have experience as engineer, as manager or in enterprise architecture in current or previous occupations. This however does mean the survey did not include respondents with the perspectives of an executive or financial officer.

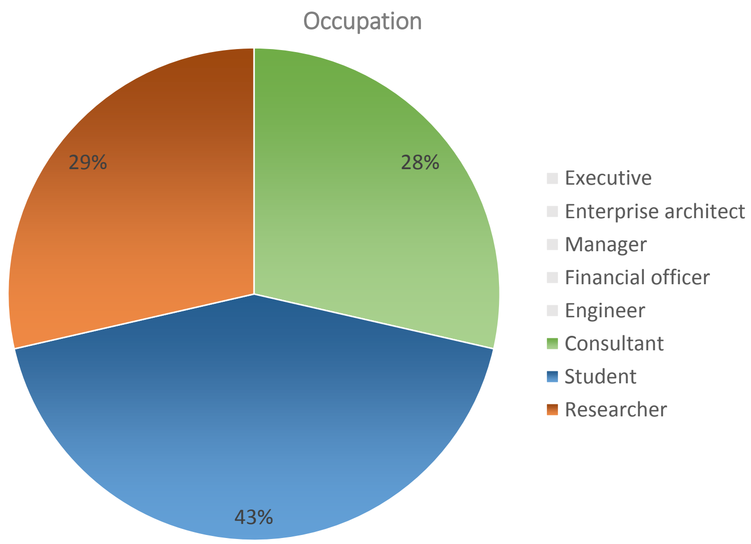


Figure 6.1: Definition Clarity

Definitions and concept

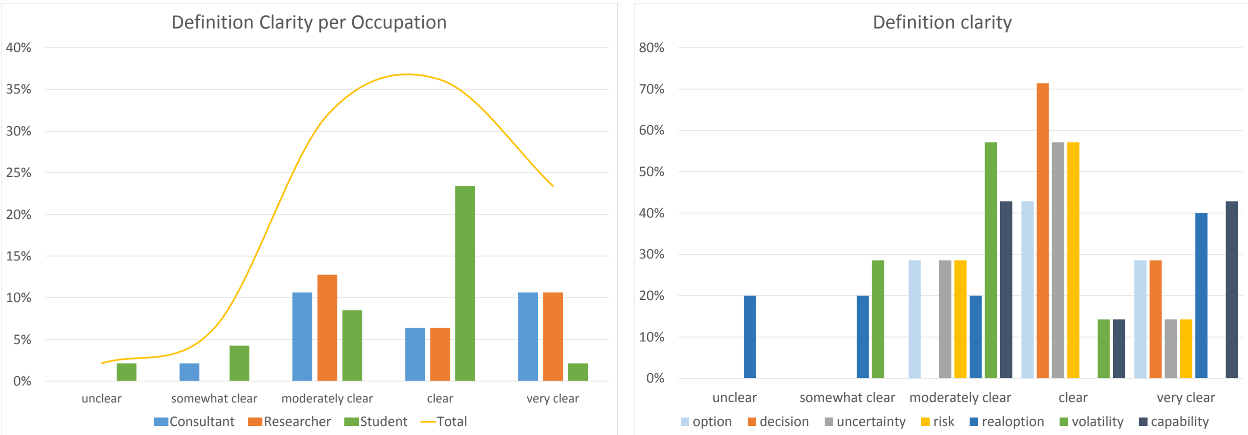
The following definitions that were introduced during the presentation are provided on the survey.

- option: the right (but not obligation) to choose
- decision: a choice on options
- uncertainty: what we don't know will happen and don't know the underlying distribution of

- risk: what we don't know will happen but we do know the underlying distribution of
- real option: option giving future flexibility
- volatility: standard deviation of (a) value
- capability: level of ability to perform

Respondents were asked to rate how well they understood these concepts in the context of the FEUD decision-making framework. Most concepts were well understood by the practitioners, rating most of the definitions as "clear" as shown in figure 6.2a. It was notable that volatility and real options received the lowest ratings and therefore it could be expected these concepts require the most support shown in figure 6.2b. No direct correlations were found in the respondent's occupation and their responses on clarity. Questions on usefulness show a strong

Figure 6.2: FEUD concepts Definition Clarity

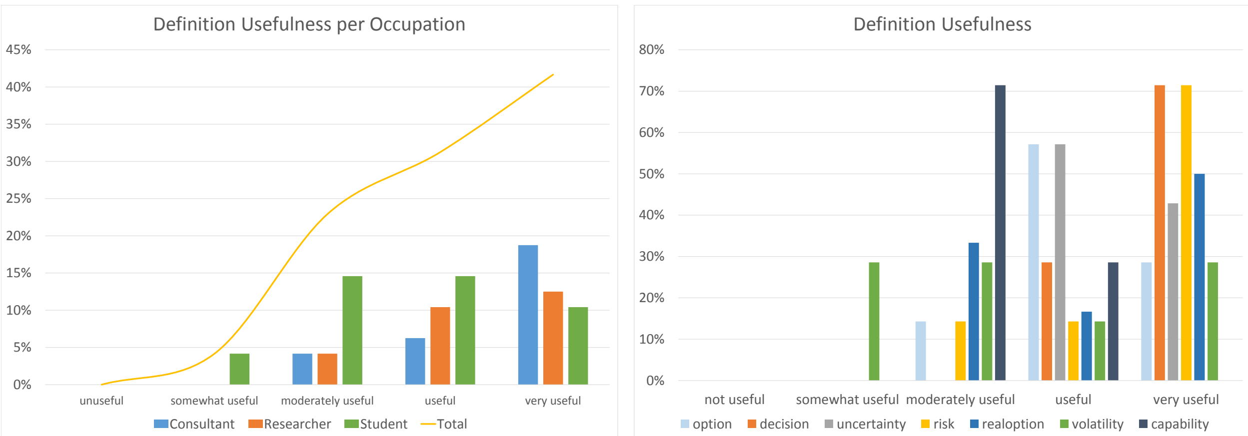


(a) Definition Clarity per Occupation

(b) Definition Clarity

tendency of the respondents toward judging the FEUD concepts to be useful in the context of EA and decision-making. Figure 6.3 displays that most respondents indicated the concepts to be "useful", also here no correlations were found with their occupation.

Figure 6.3: FEUD concepts Definition Usefulness

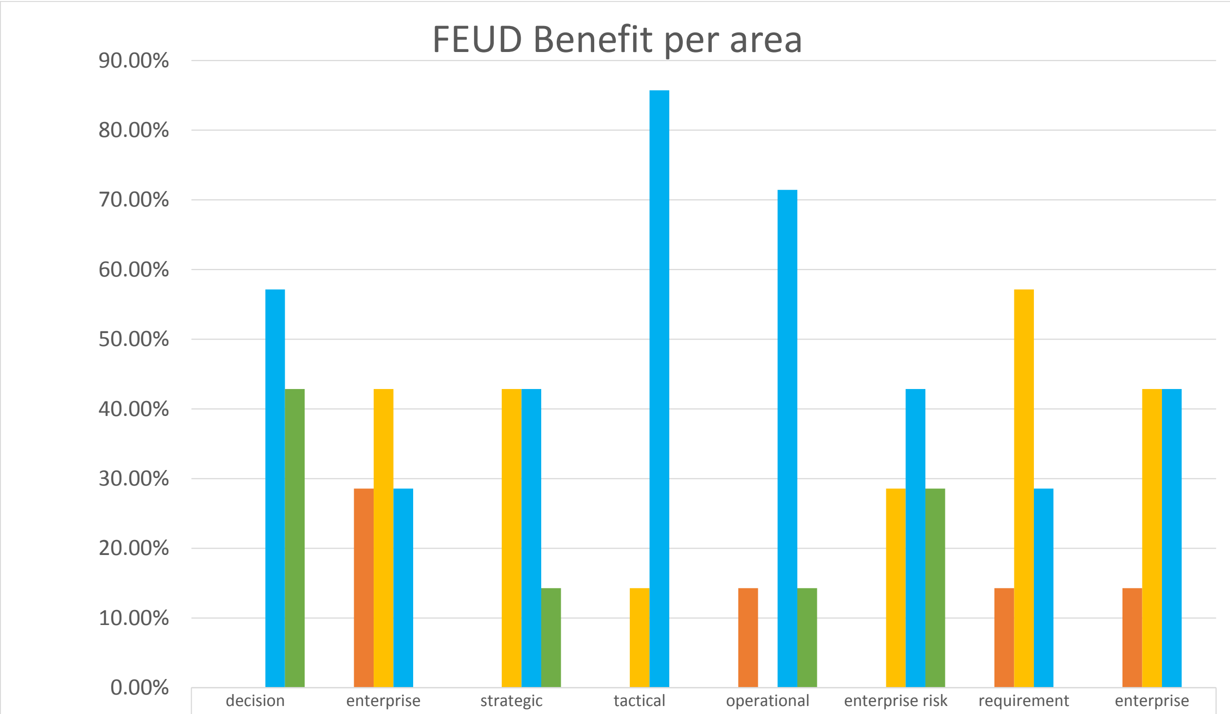


(a) Definition Usefulness per Occupation

(b) Definition Usefulness

FEUD

Response was gathered that shows how useful the respondents think the FEUD framework is for various areas related to the research. Figure 6.4 gives an overview of this response. As can



	decision making	enterprise architecture	strategic decisions	tactical decisions	operational decisions	enterprise risk management	requirement elicitation	enterprise agility
not useful	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
somewhat useful	0.00%	28.57%	0.00%	0.00%	14.29%	0.00%	14.29%	14.29%
moderately useful	0.00%	42.86%	42.86%	14.29%	0.00%	28.57%	57.14%	42.86%
useful	57.14%	28.57%	42.86%	85.71%	71.43%	42.86%	28.57%	42.86%
very useful	42.86%	0.00%	14.29%	0.00%	14.29%	28.57%	0.00%	0.00%

Figure 6.4: FEUD Benefit per Area

be clearly seen in the figure most respondents identified FEUD as moderately useful to very useful on most areas it targets. Interestingly a few respondents marked it as somewhat useful in the context of enterprise architecture however did find FEUD useful for decision-making across dimensions of the enterprise architecture. Further research is necessary to understand if this has a specific cause or is related to the presentation of FEUD.

Practitioners

The interviewees rated the framework practically useful rating it an average 3.7 out of a 5 overall score. Complexity of the framework however was rated equally high $(3.7/5)$ which can indicate that participants accept the framework's complexity and see it as necessary. Figure 6.5 gives an overview of which functions respondents see to benefit from FEUD. Remarkable is that the engineer is not seen to benefit from FEUD, however operational decisions, shown in figure 6.4, were rated as an area that could greatly benefit. This could indicate operational decisions can be further divided, e.g. into decisions made by management and those by engineers, or a clear definition of the functioning of an engineer was missing. The "other" function group contained only entries that report to the board of directors such as Chief Risk Officers and Chief Information Security Officers further indicating usefulness in the areas of Enterprise Risk Management (ERM) and Information Security.

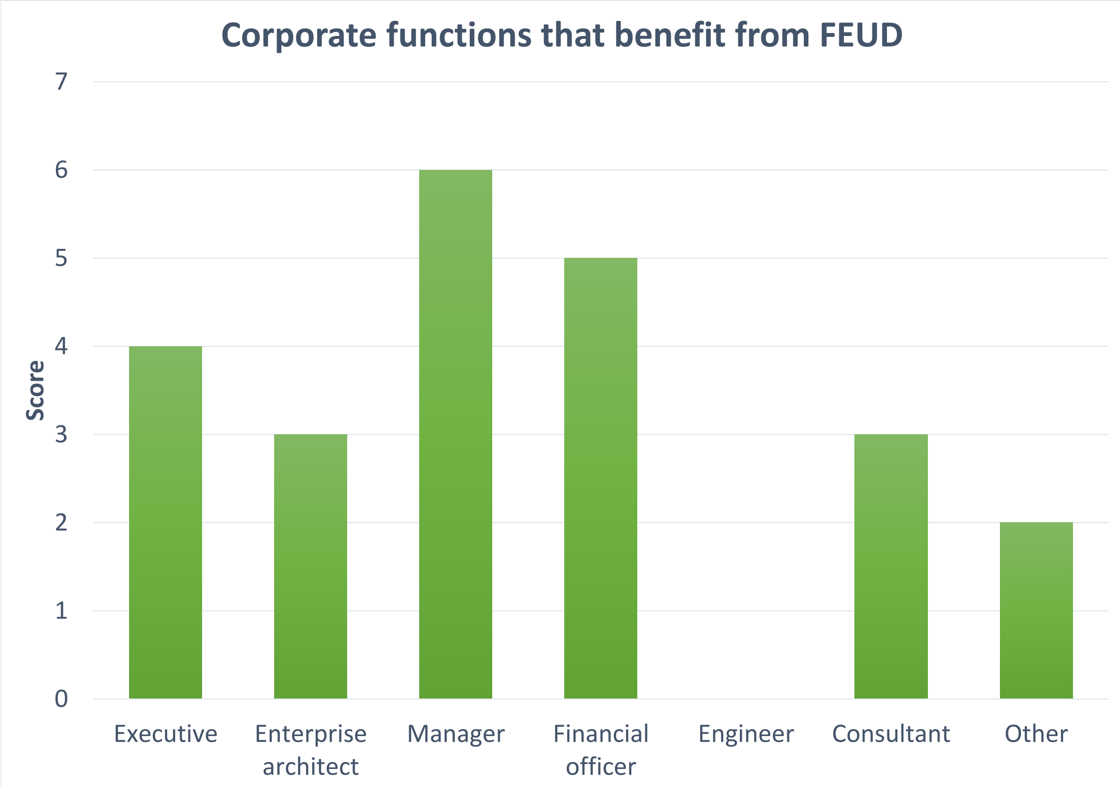


Figure 6.5: FEUD Benefit Corporate Functions

Real Option Valuation

The next section deals specifically with the Real Option Valuation (ROV) methods as demonstrated in the FEUD context. Questions were asked on the added value of ROV and most respondents agreed its demonstrated use in FEUD has added value to both decision-making, scoring an average of $3.9/5$), and enterprise architecture, scoring an average of $3.1/5$. It's notable no respondent rated the added value lower as 3 or higher than 4 and thus ROV was valued uniform across respondents. The complexity of ROV scored as very complex averaging a $4.3/5$ with only one respondent giving it a rating lower than 4.

Decision-making

Respondents were asked questions to assess opinions on the documentation of decision-making, through a framework such as FEUD, in the Enterprise Architecture modeling language Archimate. The respondents overwhelmingly agreed, rating an average $3.8/5$, that Archimate would benefit from modeling both decisions and options. Respondents also indicated that documenting decisions and options through FEUD would enhance communication between executives, enterprise architects and financial officers, averaging a $3.4/5$ rating.

6.4 Reflection

Valuable insights are drawn from this focus group session and the survey on both the FEUD artifact and the research methodology that could benefit further academic ventures in this research area and possibly other qualitative research in general. These insights are typified by the perceived strength and weaknesses of the approach as shared below, analogue to reflections performed in Daneva and Ahituv (2011), Anderson (2010). These weaknesses, if left untreated, can pose a threat to the validity of this research's results and therefore for each weakness a discussion on the available treatments and performed treatments follows.

6.4.1 Strengths of research

Detail

Due to the deliberate loose structure of the focus group approach, where its participants are jointly responsible for determining the next discussion subjects, an unprecedented depth, compared to more qualitative approaches, is obtained on items that otherwise might not have been part of the research agenda. In FEUD it was expected to see discussion on the complexity of included calculation methods (i.e. Real Option Valuation). However, the participants generated unexpected discussion on specific stakeholders' roles required in each phase, which came as a welcome discovery. While the stakeholders were identified prior to the research, as well as any perceived benefit for each stakeholder from using FEUD, as is part of the design science research approach, their specific role however in performing each phase of the framework had not been explicitly considered. These newly discovered details that could be discussed at length, provide grounds for further research and exemplify what makes focus groups useful in exploratory studies. It is expected that additional case-studies are needed to fully reach the detail required to present the framework to the industry. As a first step however the chosen research methodology allowed for a careful and flexible positioning of complexity that balanced theoretic rigor on one end with applicability on the other.

Explorative

As mentioned earlier, the research was of an explorative nature that combines existing theories with industry insights in order to create a new artifact (i.e. the framework) that aims to solve perceived problems on decision-making under uncertainty in EA. Because the research develops an artifact in the relatively unstudied area of making decisions throughout an EA, multiple fields of research were explored and the research methodology needed to support and reflect these explorations. The case-study for the virtual company Archisurance that was used previously by many researchers working for/with BiZZdesign, provided this thesis' research with a flexible yet realistic problem context. The findings of this case-study, as discussed with experts, were subsequently used to simplify the framework to its essence and presented using a non-technical example of a decision on a commute to work. These essentials and its example were further explored and validated in the focus group session.

Practical usability

By reviewing the framework in three stages, first through expert opinions, second by the focus group and third through a questionnaire filled out by practitioners, its applicability for use in the industry has been thoroughly evaluated. In particular, the complexity of the ROV calculations remained a concern and while these were demonstrated using simple spreadsheets its underlying (complex) financial computation theories are a source for concern. It was suggested that the valuation can be presented to the industry as a "black-box" tool, that presents an outcome after receiving necessary inputs. However, it is the author's opinion that this would not only diminish some of the benefits of actively modeling Real Options but also potentially create a dangerous situation where implicit assumptions greatly affect the overall valuation and the tool can be used erroneously when underlying option theory assumptions are not satisfied. More research is needed in tools that further balance the complexities of ROV while increasing the usability for users without financial computation background. The Matlab code and Excel sheets created in this project can provide an advanced starting point for this research.

6.4.2 Weaknesses of research

Dependency

The qualitative research methods used in this project all greatly rely on the individual skills of the researcher for their academic rigor. Qualitative research methodologists (e.g. Kitzinger) warn us that conclusions of qualitative studies are more easily influenced by the biases and idiosyncrasies of the researcher and greater care is needed to ensure a desired level of research quality is reached. While the ten years of industry experience, in various positions described by EA, brought in by the author meant that academic theories were always immediately related to a practical reality, greater care was taken to ensure this practical reality (as it represents just one perspective) did not dictate the full scope of the explored theories. To mitigate these concerns supervision was assembled from various academics that bridged computer science with business management systems fields and when needed computational finance. It was further performed in the context of BiZZdesign that has an established experience of modeling EA in various contexts based on extensive R&D performed in-house and in partnership with academic institutions.

Rigor

While the dependency on the author discussed in the previous section is seen to potentially affect rigor, qualitative research also has difficulty demonstrating rigor. For this reason, assumptions in this research are clearly stated and the limitations will be structurally dealt with in the next concluding chapter. Moreover, evaluation took place in three phases that leverage different approaches to minimize contamination of results. In light of this, it remains important to stress this research is of an exploratory nature and therefore the requirements for rigor differ from other research such as descriptive and casual research. Essentially no starting theory or hypothesis existed and many of the goals of the research relate to discovering correlations to form a base for such hypothesis in future research. This base of correlating theory is packaged as a designed artifact that attempts to solve various problems perceived. FEUD's evaluation therefore focused on comparing the expected effects of the artifact and its problem context with the perceived effects by various stakeholders as validated in the focus group and the survey. The questionnaire therefore is designed to test the research questions stated at the beginning of the research.

Generalizability

Analytical induction, with only the current research data, to a greater population sample remains difficult because evaluation data was gathered from a limited number of sources and based on one virtual case study. While the focus group and survey contained practitioners in different roles of an EA their overall number remains limited and key roles such as the executive were not represented in the focus groups or survey. However by basing the framework on proven frameworks and standards such as TOGAF, Archimate and ISO 31000:2009, as well as take industry best practices (e.g. Deloitte's risk assessment white paper (Curtis & Carey, 2012)) into consideration it is more likely that FEUD will fulfill future requirements for generalization (Roel Wieringa & Daneva, 2015; R. J. Wieringa, 2014). As indicated in the Focus Group discussion above, Real Options have already found practice in various industries such as Oil & Gas and pharmaceutics and it is therefore expected that these industries familiar with the computational complexities could provide a great point-of-entry for additional case-studies.

Time consuming

While it can be argued that setting up experiments requires more time than organizing a focus group, the information retrieved from focus groups often requires many iterations and takes considerable time to digest. Statistical inference is typically not available and therefore presenting conclusions can not rely on the various statistical visuals to describe findings.

Neutrality

A key constant during the entire research and most of its evaluation has been the presence of the researcher. This can affect the responses during data gathering and, even subconsciously, instill bias. As the research was supervised by focus group experts, the focus group approach was discussed prior to minimize bias. Key aspects were to not give opinions as a moderator and remain neutral in appearance, behavior and language.

Privacy

Focus groups represent a difficult approach to retrieve private or anonymous information because of its directness in interaction, unless performed online. This can lead to confidentiality issues and to participants that do not share their whole-story in anticipation of such confidentiality issues. While the present research gave no indication of these issues, the questionnaire was made consciously anonymous with the ability to provide comments of which only one respondent took advantage. Whether an online questionnaire (on Google Forms) would represent an accepted format for a practitioner to share her/his private information is also called into question.

Chapter 7

Conclusion

This chapter reconsiders the research questions stated in chapter 2 and discusses the results and conclusions as well as provides recommendations for future research that can be drawn from this research.

7.1 Discussion of contribution

This thesis introduced a framework for enterprise uncertainty-driven decision-making (FEUD) that is aimed to co-exist and extend Enterprise Architecture Frameworks (EAFs). It provides a comprehensive structure that supports taking complex decisions that deal with uncertainty holistically in an Enterprise Architecture (EA) context. The framework is centered around a decision-making process that pro-actively deals with uncertainty and is shown to effectively integrate with risk management and risk treatment design. Uncertainty identification in FEUD is tied to business analysis and capability management principles and provides a practical bridge with existing risk management standards. Real Option Valuation (ROV) is positioned in this context as one of the risk treatment strategies. It can be leveraged to mitigate risks by investing and designing for flexibility and leverages prior work that has analyzed real options but failed to provide this context. It is exactly this context that initiated the development of a decision-making framework when no such frameworks were found in EA literature. While the design of the framework therefore was exploratory much attention was put to ensure the framework remained simple yet powerful (i.e. it is generic enough to support most types of decision-making). Because EA benefits greatly from (visual) modeling languages, such as Archimate, an extension to Archimate is proposed with decision-making constructs (i.e. options and decisions). Ultimately a structured decision is made using a strategy that can include both qualitative and quantitative arguments. Such strategies are integrated into the framework and therefore the process and existing decision strategy literature is leveraged.

7.2 Addressing research questions

The research questions posed in section 2.4 are reviewed and addressed.

RQ1: How can complex EA investment decisions be modeled in an enterprise? No existing frameworks could be leveraged that provide a process that supports holistic decision-making under uncertainty in an EA. Some research exists that provides a framework for the holistic use of ROV in an EA and other literature exists that proposes an uncertainty-driven software acquisition process through ROV. This framework integrates and extends these by providing a context for ROV among other risk treatments, and leverages existing ERM standards in combination with capability and business analysis theory for a process that pro-actively deals with uncertainty. Because typical EAFs deal with EA holistically the decision-making framework is designed to be used in combination with existing EAFs, most notably TOGAF with Archimate.

- **How are EA decisions made holistically throughout an enterprise?** By clearly defining EA decisions and options and integrating it with EAF modeling constructs they can be included in the modeling of an EA. Decisions are the choices on options or composed of decisions, options are composed of EA elements. The EA elements can be from any EA dimension (strategic, tactical, operational) and thus options represent holistic entities across an enterprise.
- **What (types of) problems do decision-makers encounter when making architectural decisions?** Uncertainty affects all architectural decisions as these decisions typically requires forecasting. Most decision-making currently takes place without structure, is based on expert-opinion or gut-feeling, and not documented.
- **How are EA decisions related to investment options and alternatives?** An EA model can be viewed as the result of a chain of decisions. Decisions can be represented as choices on investment options that are expected to generate value.
- **How can decisions, options and alternatives be modeled?** By leveraging the Archimate EA modeling language a decision-making extension was included in the FEUD framework that supports decisions, options and alternatives in an EA context. Researching their applicability outside the EA context was not within scope of this research.
- **What creates uncertainty in an EA?** Uncertainty can be sourced endogenously or exogenously. The endogenous sourced uncertainty can be related directly to capability (or the lack of) while exogenous uncertainty is sourced in the environment and can be discovered through a business context analysis.
- **How does uncertainty affect EA decisions?** Uncertainty, unlike risks, if high and left untreated is seen to lock-up decision-making. Uncertainty, in particular if designed for, can provide both risks and opportunities that EA decisions can account for or take advantage of.
- **What value quantification methods exist for EA?** Various valuation methods, in particular on a strategic dimension, exist but with limited integration within EAFs. Most EAFs focus on modeling EA assets (strategy, processes, systems, etc.) and EA transitions but leave quantification methods outside their framework.
- **What are current problems with value quantification in EA?** EA models face uncertainty due to their complexity and the increasing difficulty of predicting future events they need to respond to. Uncertainty in EA has never been structurally dealt with and can cause unexpected risks to manifest with potential disastrous results.
- **What decision-making strategies exist?** As shown in section 3.3 decision-making strategies can be broadly categorized into compensatory or noncompensatory strategies. Numerous strategy (formulation) models exist, such as the SWOT analysis, Porter's Five Forces framework, Marketing Mix and the Business Model Canvas to name just a few, created to assist decision-makers in formulating a strategy. Their relationship to decision-making strategies such as conjunctive, elimination by aspects, and satisficing as formulated in (Payne et al., 1986; Rothrock & Yin, 2008) is outside the scope of this research. Decisions on other dimensions of EA have received less focus by models and literature and FEUD is the first framework to consider EA decisions holistically. It is likely that only a combination of strategies is able to support the full complexity of

EA decision-making. It is proposed that the more operational an EA decision becomes, and the easier it is to determine the cost attributes of decisions, the more compensatory decision-strategies become feasible. Reversely the more strategic a decision, and the more complex (business) value will determine decisions, the more noncompensatory decisions become relevant. FEUD was designed with an open structure to support strategies or combinations of strategies of both types.

RQ2: What is an architecture based ROV method? ROV has seen its origins and use in the valuation of strategic investments and has been proposed for use in EA by Mikaelian (2009). ROV can support decision-making by valuating flexibility. Flexibility is identified as one of the risk treatment, including positive risk, categories. ROV can therefore support risk-mitigation for investment options and increase the option value used in EA decision-making. FEUD provides the framework to make these decisions that can leverage ROV to better value high risk decisions holistically in an EA.

- **How does ROV value EA investments?** ROV values flexibility and includes it in the investment valuation.
- **How can ROV account for uncertainty in EA?** Uncertainty is represented as the volatility of the value of an investment over time. The higher the uncertainty, the bigger the possible difference between the forecasted minimum and maximum returns.
- **What ROV calculation methods exist?** Section 3.8.2 shows various methods that can be categorized in three main techniques: Partial differential equations, Simulations, and Lattices. While all can be used to value flexibility some are more appropriate than others. The Black-Scholes equation for example is easy to calculate but little transparent and only allows for flexibility at the end of an options maturity, which is not typical for the flexibilities needed to respond to risks in EA. A Monte Carlo simulation in respect to ROs, as described by Triantis and Borison (2001), is both difficult to standardize for all types of ROs, computationally complex and useful when cash flows from a project depend on prior decisions (Aarle, 2013). Lattices on the other hand provide a visual method that, in particular with use of software, allows for the modeling of real options while immediately viewing the results. Although the underlying calculations, with similar concepts to those in Black-Scholes, are complex it shields these off and allows decision-makers to focus on identifying and designing the flexibilities. While FEUD does not prescribe any calculation method, binomial lattice calculations based on Copeland and Antikarov (2003) have been used because of the above mentioned transparency.
- **How can ROV support integrated EA decisions?** No decision in an EA is limited to just one dimension, its effects are holistically by nature. By providing valuation calculations for these decisions ROV needs to take account of this integrated nature. If one decision leads to another and a decision-chain is build, it would be impossible that the valuation (with or without ROV) does not end up as an input in the valuation of the first decision. FEUD represents these as decision-chains where investment costs flow downward into more reified EA layers and value flows upward into more abstract EA layers.

RQ3: How can the EA decision-making process be structured? No decision-making process was found in literature that supports making EA decisions that deal with uncertainty. Research by Olagbemiro (2008) suggests to include an uncertainty elicitation phase early in a software acquisition process. FEUD incorporates an uncertainty identification phase that analyzes the uncertainty of each feasible option that was discovered in a decision investigation phase. With uncertainties identified these can be made tangible by distilling risks from them through a risk assessment process with steps similar to those provided by ISO 31000:2009.

Effectively selecting risks for treatment requires an understanding to which risks the enterprise has the greatest vulnerability. These risks are focused on in the next phase of the treatment design. In a treatment design one of treatment options can be selected (avoidance, reduction, sharing or retention) for each risk. ROV methods provide a way to hedge the risks by investing in flexibility options and fall under the retention treatment strategies. With all the options, their risks and possible treatments available the decision maker can start to valuate each option. This entails establishing cash-flows and including their risks. If reductions were designed these need to be inserted and for ROs binomial lattices can be build to value flexibility. Ultimately a decision needs to be made in the last phase of decision making. Depending on the strategy this can require many or just one criteria (e.g. value) and can include non-quantifiable criteria.

- **What are the phases of EA decision-making?** As mentioned above these can be an iterative cycle of:

    1. EA decision investigation
    2. Uncertainty identification
    3. Risk assessment
    4. Risk treatment
    5. Option valuation
    6. Decision making

- **How can decision-making deal with uncertainty?** By including uncertainty identification early in the process and by distilling risks from these uncertainties such that risk treatments can be designed prior to decision making.

- **How can available ROs be discovered?** In practice it is likely that this requires experience as not all real option types are feasible for every company and in every investment decision. Although much literature exists with different examples of ROVs more research is required on which RO types are applicable to EA and in what circumstances and for what kind of risks.

- **When and how can ROV methods be integrated in a decision-making process?** ROV is a method that treats risks by mitigating vulnerability by exposing the investment to potential flexibility. ROV methods should not be used if no risks and thus no uncertainty exists, i.e. when it's a simple decision.

- **How can the (real) options be included in EA decision-making strategies?** ROV ultimately provides a valuation of an option that includes potential flexibilities. This value is then used as an attribute on which criteria can be formed in the decision-making strategy.

7.3 Limitations

The following limitations and assumptions were made in this research:

- Requirements engineering: The framework does not discuss the specifics of various Requirement Engineering (RE) methods and instead assumes a list of requirements is available to the framework. The identified options could be seen as the different ways (in various gradations) to fulfill these requirements. The relationship between non-functional requirements, functional requirements, and their priorities are expected to influence the decision criteria and strategy.

- Decision graph: As explained in the framework an EA model can be viewed as the result of a tree of decisions. Viewing the EA layered in dimensions sees decisions in a more abstract layer umbrella decisions on a lower more reified layer. In this parent-child relationship it is clear that the investment in a higher decision can not exceed the investments on a lower layer, reversely the expected value of an investment on a lower layer can not exceed those of a higher layered decision. FEUD support these chains of decisions by taking the investment attribute of a higher decision down the EA model tree, while aggregating the value back up higher into the tree. This requires an iterative process that updates the high levels once lower level decisions are made or adjust the lower levels if the higher levels are updated. However, many more decision relationship types, besides simple parent-child relations, are possible. It is expected decisions throughout an enterprise will realistically be able to form a complex graph structure, however the ramifications of these types of relationships have not been further explored in FEUD.

- Limited evaluation: The framework has been evaluated, alongside other qualitative methods such as focus groups, by use of a survey with a relatively low response rate. Both the survey and focus group included respondents in the roles of Enterprise Architect, Researcher, Consultant, and students. Notably absent roles are practitioners in Executive (e.g. CEOs) and Financial roles (e.g. CFOs). The respondents however did predict the FEUD framework to be useful for all these roles.

- Virtual case study: the used case study that demonstrates the framework in Archisurance, while realistic, was not real. Instead it was supervised by academic and industry experts to ensure a feasibility of proposed concepts. Full case studies, of different sizes and in different contexts, are required to better predict the usefulness of all contributions.

- Decision making strategy: The examples demonstrated in this thesis of decision-making, the last phase in the process, all have quantified attributes in the form of monetary value. While the criteria of the discussed strategies can contain qualitative attributes this has not been demonstrated. Decision-making has a foundation in the academic fields of psychology and neuroscience that is extensive and relatively unresearched in regards to EA or IT models or frameworks.

- Risk assessment and treatment: The risk assessment and treatment phases have been based on the ISO 31000:2900 standard. ISO 31000:2009 provides generic guidelines for risk management and therefore is very suitable for adoption in a generic decision-making framework. Other more specific risk management frameworks exist, such as COSO for ERM and SABSA that targets a security architecture. Integration with these specific frameworks is beyond the scope of this research.

- Real option valuation: New methods exist in literature that extend or improve on the principal valuation method proposed by Copeland and Antikarov (2003). Evaluating all ROV methods and their effects on the decision-making framework was beyond the scope of this thesis, the framework is intended to be generic to these methods but other research will need to confirm.

- Enterprise Architecture Frameworks: A deliberate emphasis in this thesis was put on its use in combination of TOGAF and Archimate EAFs, both open EA standards from the Open Group. Implementing the framework with other EAF's was outside the scope of this research. Zachman's EA Framework however presents a taxonomy of the EA assets on which FEUD supports decision-making.

- Exogenous uncertainty: The framework is demonstrated by discovering exogenous uncertainty from sources identified by a PESTLE analysis. Various business analysis methods exist, this research demonstration has been limited to PESTLE because of its clear focus on external sources and widespread use in the industry.

- Generalizability: As discussed in the evaluation section the framework and its concepts have a perceived validity within the current research context but require additional validation to prove its generalizability for example to EA decision making in different industries, in support different frameworks, in relation to other financial evaluation methods and in enterprise of different sizes and cultures.

7.4 Recommendations

This section presents the recommendations to address the limitations in the scope of this research.

- Enterprise Agility: It is proposed that designing EA around uncertainty by designing flexibility intrinsically into a design ultimately decreases the costs of responding to future events by increasing "Enterprise Agility". FEUD attempts to support EAFs by dealing with uncertainty and the design of flexibility explicitly in the decision-making process. Future research should attempt to measure and provide further evidence FEUD increases Enterprise Agility by providing a framework that increases business value of EA models through flexibility.

- EA communication: Future work can investigate if the proposed framework enhances communication on EA between stakeholders. By viewing an EA model as a set of investment decisions that attempts to maximize business value it is expected to relate EA better to the perspectives of executives and financial departments. FEUD attempts to bridge the often model-based perspectives of Enterprise Architects with the decision-based reality of decision-makers.

- EA story: People have an innate ability to relate to stories. EA models typically only represent states of an enterprise at specific moments in time, i.e. through target, plateau and base-line models. A gap analysis provides a method of analyzing what needs to be build and jumps from one such state to another. It can therefore be seen as an instrument that adds a time perspective to EA modeling. EA models however currently only have a limited ability to model, capture/document the decisions that provide an insight into why these EA states exists or are targeted and why other states were or are not. It is proposed that capturing and modeling EA decisions and options is a first step into building a (rich) EA story which provides an artifact that stakeholders can better relate to, enhances the communication between stakeholders and therefore is expected stakeholders are more likely to invest in. Current EA models, and in particular Archimate, should be extended to convey these concepts. The FEUD framework provides meta-model suggestions for capturing EA options, uncertainty and decisions in Archimate in (new) relations to already proposed concepts that include capability and risk. Full representation of an EA story requires the implementation of an EA time-perspective as discussed in the next item.

- EA time-perspective: EA models such as Archimate represent time through a current (baseline) state, a desired (target) state and various intermediary (plateau) states. The tasks necessary to get from one state to another are captured in the Implementation and Migration Extension through deliverables and work-packages. It can be argued that (only) the completion of a deliverable unlocks business value and therefore that the actual value of a project under development is the sum of the values of delivered deliverables. The use of Real Options requires the monitoring of this actual value against estimated values and execute/activate the invested flexibilities once certain value limits are reached (either too low or too high). More research is required that focuses on the aspects of time in EA models, such as Archimate, and how time can be used to monitor value and Real Options. The binomial lattice model used to model real-options, which effectively models the possible outcomes of an investment into the future, represents a powerful visualization that includes this time-perspective. More research is required on how this and time-concepts in general can be included in current Archimate models. Because of perceived complexity it is expected that successful EA modeling along a time-line, especially when including probabilities as is seen in binomial-trees, requires support of EA tools such as Architect that can hide the calculation complexities from the models. Appendix F shows examples of various diagrams that attempt to conceptualize some of these aspects. Estimated Net Present Values would need to be compared to the actual values, by for example gathering quarterly status updates and estimates from all involved projects, as if walking through the binomial lattice in order to see whether Real Options need to be executed.

- Real Option Valuation methods: As mentioned in the limitation section of this thesis many ROV methods have been proposed, some that claim to enhance volatility estimates, others that provide different ways of representing future probabilities and those that are more suitable for different inputs. While FEUD is generic enough to support most of these, more research is needed that compares these methods to understand their effects and application within the context of EA decision-making under uncertainty.

- Decision-strategies under uncertainty: The decision strategies mentioned in this thesis do not explicitly consider uncertainty. While the FEUD framework attempts to address uncertainty by distilling risks for treatment it is anticipated that options still retain certain amounts of uncertainty. Additional research is required to research the effects of uncertainty and risks in decision-making strategies and in particular the (expected) benefits of the proposed translation of uncertainty into risk.

7.5 Summary

The framework introduced in this research is positioned at the intersect of EA, decision-making, and financial evaluations. As such it combines theories from various academic disciplines in order to improve the decision-making in EA that addresses both academic and practitioner's concerns. Because no framework currently exists that addresses modeling decisions in and throughout an EA, many new concepts were explored and integrated. FEUD successfully makes a connection between the concepts of uncertainty, capability, business-analysis and risk. Practitioners that evaluated FEUD, both those that took part in the focus group session as well as the respondents of the questionnaire, overwhelmingly agreed to the usefulness of these concepts, their mutual relations and their use in EA as well as with decision-making. While the framework represents a prototype that still has to prove its value in the industry, this positive feedback gives confidence for implementation and also provides grounds for further development and research as set out in section 7.4. As mentioned in the limitations section, many areas of the framework can receive further investigation. It is important to note that FEUD represents a framework and therefore its very nature is to provide a structure that provides opportunities to include various additional tools and methods. It was exactly such context that was often lacking in much RO research and a gap FEUD attempts to fill. ROV, as was also confirmed in the evaluation, is perceived as a complex valuation tool that requires both a financial and computational background to fully fathom its intricacies. In this research the valuation calculations were however performed using simple spreadsheet software and the use of binomial lattices made modeling of the ROs more transparent and easy. EA modeling tools could leverage such spreadsheets and model the ROs without subjecting end-users to the underlying details and complexity. Such black-box applications do come with additional risks, by loosing transparency chances for misinformed/wrong presumptions increase. The monitoring of ROs, required for their execution, through automation would require the inclusion of a time dimension currently not present in EAF tooling. The inclusion of such a dimension in the current, mostly two dimensional, EA models, such as those by Archimate, would require significant research and development of supportive tooling to remain manageable and effective. While providing a context FEUD does not provide specific implementation for this other than the aforementioned spreadsheets and Matlab prototype, which for now can be manually updated with actual information once it becomes available. FEUD bridges the domains of executives (CEO, CFO, CIO, CTO, CSO, etc.) and Enterprise Architects. By focusing on decision-making it translates the EA-model into a set of decisions of investment with a perceived value that is expected to enhance communications between and to stakeholders. This should allow enterprise architects to better justify investments into long-term high-risk EA projects. Whether FEUD is successful in providing a framework for this communication remains to be validated as this research's evaluation sample was too limited to draw such conclusions. The focus groups did point out that more research is warranted into the roles required in each phase of the decision-making cycle. An investigation of how FEUD relates to current Enterprise Governance frameworks could provide a practical starting point for this research. While integrating the Enterprise Risk Assessment practices into the FEUD framework it was found that ERM practices take place and affect all stages of the TOGAF ADM. The research therefore proposed to include a Risk-management repository, analogue to the Requirements-management repository, that puts ERM in a central position accessible to- and providing input in- all ADM phases. The risk-management repository should also cover risk treatments and therefore could create a knowledge-base that can be leveraged in future decisions. Much of the probability estimations, in particular those used in ROs, would greatly benefit from historic data. Evident in the evaluation was a desire for a structured decision-making framework that exists among both industry specialists and researchers. Whether FEUD, while ambitious, is able to fully provide a structure for all types of EA decisions remains to be validated. The indications have been positive, and the generality of FEUD, and its integration of proven standards, provides a solid foundation for further research in how to improve EA decisions, in particular when they deal with large amounts of uncertainty.

Appendix A

Archisurance tables and lattices

Table A.1: Archisurance Development Option Logarithmic Present Value Approach

Time period	Cash Flows (€100K)	Present Value (€100K) at Time 0	Present Value (€100K) at Time 1
0			-
1	-30.00	$\frac{-30.00}{(1+13\%)^1} = -26.55$	$\frac{-30.00}{(1+13\%)^0} = -30.00$
2	-8.00	$\frac{-8.00}{(1+13\%)^2} = -6.27$	$\frac{-8.00}{(1+13\%)^1} = -7.08$
3	16.95	$\frac{16.95}{(1+13\%)^3} = 11.75$	$\frac{16.95}{(1+13\%)^2} = 13.27$
4	45.97	$\frac{45.97}{(1+13\%)^4} = 28.19$	$\frac{45.97}{(1+13\%)^3} = 31.86$
5	80.40	$\frac{80.40}{(1+13\%)^5} = 43.64$	$\frac{80.40}{(1+13\%)^4} = 49.31$
Sum		50.77	57.37
Return ratio	$\ln(\frac{50.77}{57.37}) = 0.1222$		

Table A.2: Archisurance Binomial lattice for 5 period development option (in €100K)

0	1	2	3	4	5
0.77	1.38	2.49	4.48	8.06	14.51
	0.43	0.77	1.38	2.49	4.48
		0.24	0.43	0.77	1.38
			0.13	0.24	0.43
				0.07	0.13
					0.04

Table A.3: Archisurance Decision lattice for 5 period development option in (€100K)

0	1	2	3	4	5
2.32	2.67	3.50	5.19	8.44	14.51
	1.79	1.86	2.11	2.87	4.48
		1.41	1.25	1.18	1.38
			1.10	0.82	0.50
				0.82	0.50
					0.50

Table A.4: Archisurance Merge Option Logarithmic Present Value Approach

Time period	Cash Flows (€100K)	Present Value (€100K) at Time 0	Present Value (€100K) at Time 1
0			-
1	$-33.00	$\frac{\$-33.00}{(1+13\%)^1} = \$-29.20$	$\frac{\$-33.00}{(1+13\%)^0} = \$-33.00$
2	$-14.30	$\frac{\$-14.30}{(1+13\%)^2} = \$-11.20$	$\frac{\$-14.30}{(1+13\%)^1} = \$-12.65$
3	$6.72	$\frac{\$6.72}{(1+13\%)^3} = \$4.66$	$\frac{\$6.72}{(1+13\%)^2} = \$5.26$
4	$30.78	$\frac{\$30.78}{(1+13\%)^4} = \$18.88$	$\frac{\$30.78}{(1+13\%)^3} = \$21.33$
5	$58.75	$\frac{\$58.75}{(1+13\%)^5} = \$31.89$	$\frac{\$58.75}{(1+13\%)^4} = \$36.03$
Sum		$15.02	$16.97
Return ratio	$\ln(\frac{\$15.02}{\$16.97}) = 0.1222$		

Table A.5: Archisurance Binomial lattice for 5 period Merge option in (€100K)

0	1	2	3	4	5
0.02	1.03	0.05	0.07	0.11	0.17
	0.01	0.02	0.03	0.05	0.07
		0.01	0.01	0.02	0.03
			0.01	0.01	0.01
				0.00	0.01
					0.00

Table A.6: Archisurance Decision lattice for 5 period Merge option in (€100K)

0	1	2	3	4	5
0.90	0.85	0.80	0.35	0.26	0.17
	0.85	0.80	0.31	0.20	0.07
		0.80	0.29	0.17	0.03
			0.29	0.16	0.01
				0.15	0.01
					0.00

Table A.7: Archisurance Outsource Option Logarithmic Present Value Approach

Time period	Cash Flows (€100K)	Present Value (€100K) at Time 0	Present Value (€100K) at Time 1
0			-
1	$-23.80	$\frac{\$-23.80}{(1+13\%)^1} = \$-21.06$	$\frac{\$-23.80}{(1+13\%)^0} = \$-23.80$
2	$-10.70	$\frac{\$-10.70}{(1+13\%)^2} = \$-8.38$	$\frac{\$-10.70}{(1+13\%)^1} = \$-9.47$
3	$4.72	$\frac{\$4.72}{(1+13\%)^3} = \$3.27$	$\frac{\$4.72}{(1+13\%)^2} = \$3.70$
4	$22.93	$\frac{\$22.93}{(1+13\%)^4} = \$14.07$	$\frac{\$22.93}{(1+13\%)^3} = \$15.89$
5	$44.53	$\frac{\$44.53}{(1+13\%)^5} = \$24.17$	$\frac{\$44.53}{(1+13\%)^4} = \$27.31$
Sum		$12.07	$13.64
Return ratio	$\ln(\frac{\$12.07}{\$13.64}) = 0.1222$		

Table A.8: Archisurance Binomial lattice for 5 period Outsource option in (€100K)

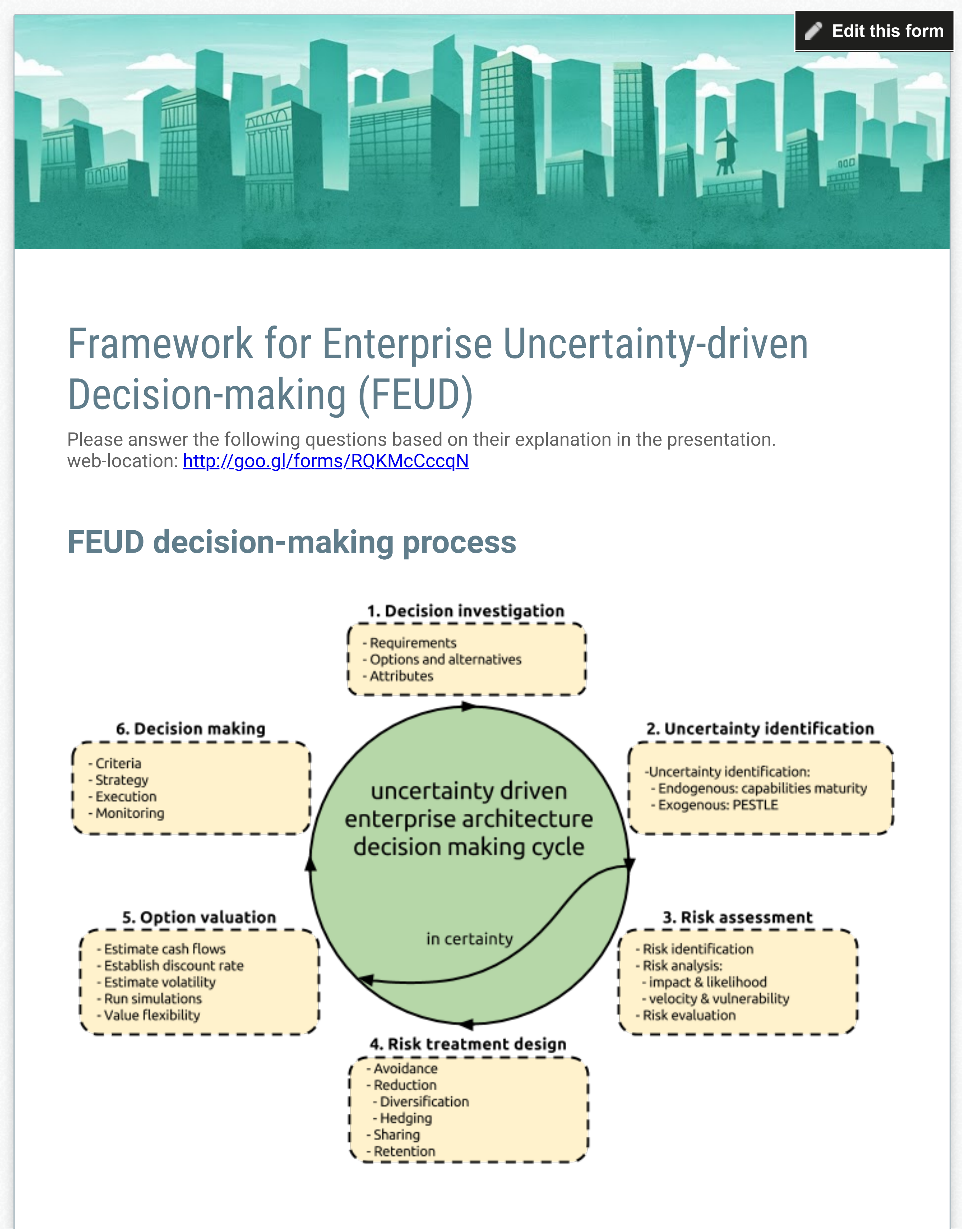
0	1	2	3	4	5
2.07	3.01	4.40	6.41	9.35	13.63
	1.42	2.07	3.01	4.40	6.41
		0.97	1.42	2.07	3.01
			0.67	0.97	1.42
				0.46	0.67
					0.31

Table A.9: Archisurance Decision lattice for 5 period Outsource option in (€100K)

0	1	2	3	4	5
2.08	3.02	4.40	6.41	9.35	13.63
	1.45	2.08	3.01	4.40	6.41
		1.06	1.44	2.07	3.01
			0.87	1.05	1.42
				0.87	0.87
					0.87

Appendix B

Questionnaire



Edit this form

Framework for Enterprise Uncertainty-driven Decision-making (FEUD)

Please answer the following questions based on their explanation in the presentation.
web-location: http://goo.gl/forms/RQKMcCccqN

FEUD decision-making process

Figure B.1: FEUD survey page 1

Personal

What is your name? (optional)

What function best describes your current work position?

- Executive
- Enterprise architect
- Manager
- Financial officer
- Engineer
- Consultant
- Student
- Researcher
- Other:

Definitions

Consider the following definitions:
-option: the right (not obligation) to choose
-decision: a choice on options
-uncertainty: what we don't know will happen and don't know the underlying distribution of
-risk: what we don't know will happen but we do know the underlying distribution of
-real option: option giving future flexibility
-volatility: standard deviation of (a) value
-capability: level of ability to perform

How clear are the concepts and their definitions in relation to the FEUD?

	unclear	somewhat clear	moderately clear	clear	very clear
option					
decision					
uncertainty					
risk					
real option					
volatility					
capability					

How useful are the concepts for the FEUD?

Figure B.2: FEUD survey page 2

	not useful	somewhat useful	moderately useful	useful	very useful
option	○	○	○	○	○
decision	○	○	○	○	○
uncertainty	○	○	○	○	○
risk	○	○	○	○	○
real option	○	○	○	○	○
volatility	○	○	○	○	○
capability	○	○	○	○	○

Context

How useful do you rate the FEUD in relation to the following?

	not useful	somewhat useful	moderately useful	useful	very useful
decision making	○	○	○	○	○
enterprise architecture	○	○	○	○	○
strategic decisions	○	○	○	○	○
tactical decisions	○	○	○	○	○
operational decisions	○	○	○	○	○
enterprise risk management	○	○	○	○	○
requirement elicitation	○	○	○	○	○
enterprise agility	○	○	○	○	○

Practitioners

The FEUD will be useful for practitioners?

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Figure B.3: FEUD survey page 3

How complex do you rate the FEUD?

	1	2	3	4	5	
very simple	◯	◯	◯	◯	◯	very complex

Which corporate functions can benefit from a FEUD?

- ☐ Executive
- ☐ Enterprise architect
- ☐ Manager
- ☐ Financial officer
- ☐ Engineer
- ☐ Consultant
- ☐ Other: ________

Real Option Valuation

Real option valuation adds value to the decision-making process?

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

Real option valuation can add value to enterprise architecture development?

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

How complex do you rate Real Option Valuation?

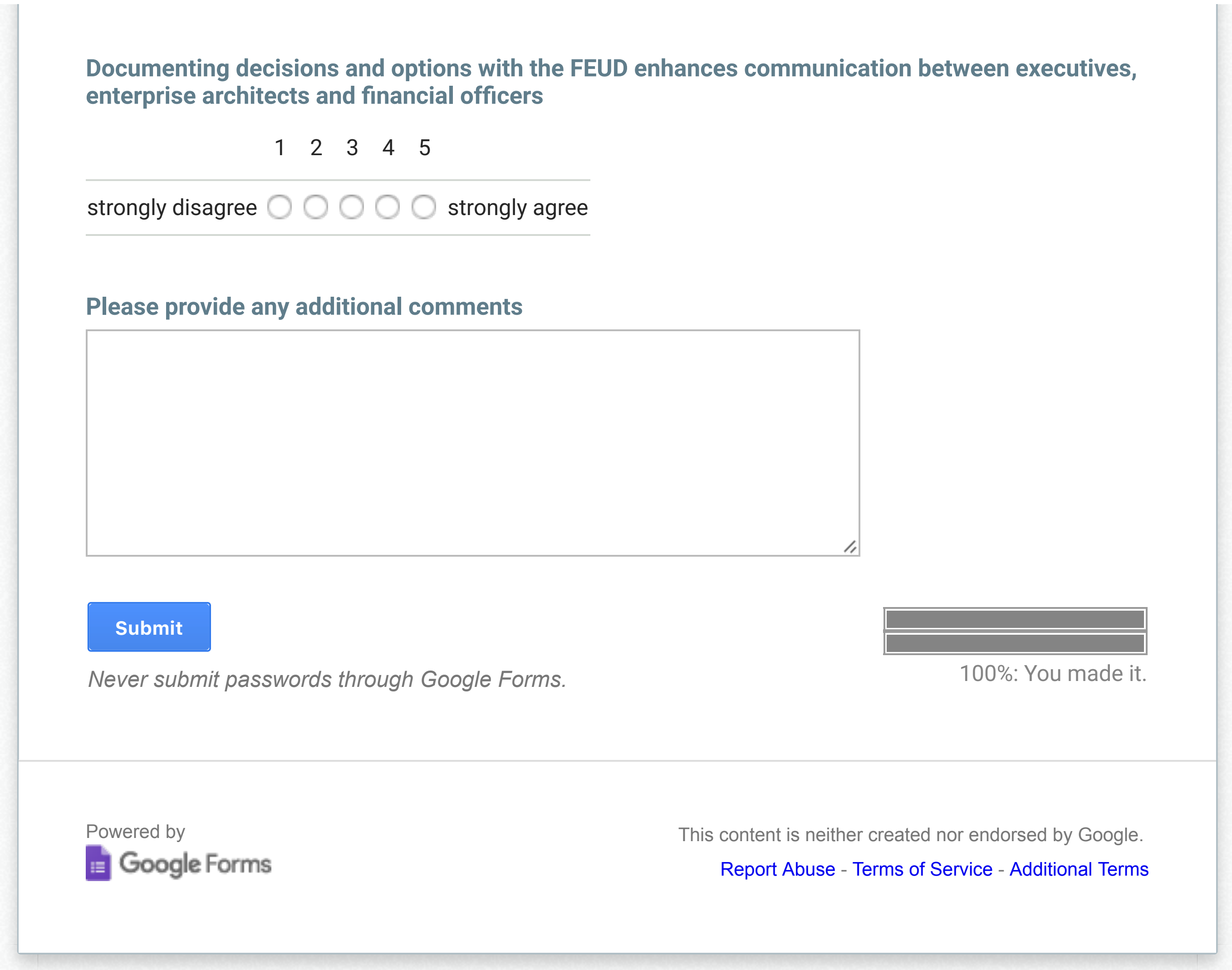
	1	2	3	4	5	
very simple	◯	◯	◯	◯	◯	very complex

Documentation

Documenting decisions and options with the FEUD in Archimate is useful?

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

Figure B.4: FEUD survey page 4



Documenting decisions and options with the FEUD enhances communication between executives, enterprise architects and financial officers

	1	2	3	4	5	
strongly disagree	◯	◯	◯	◯	◯	strongly agree

Please provide any additional comments

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Figure B.5: FEUD survey page 5

Appendix C

Risk Analysis Criteria

Table C.1: Template for risk impact scale from Curtis and Carey (2012)

Rating	Descriptor	Definition
5	extreme	▪ financial loss of $________or more ☐ international long-term negative media coverage; game-changing loss of market share ☐ significant prosecution and fines, litigation including class actions, incarceration of leadership ☐ significant injuries or fatalities to employees or third parties, such as customers or vendors ☐ multiple senior leaders leave
4	major	▪ financial loss of $____________up to $________ ☐ national long-term negative media coverage; significant loss of market share ☐ report to regulator requiring major project for corrective action ☐ limited in-patient care required for employees or third parties, such as customers or vendors ☐ some senior managers leave, high turnover of experienced staff, not perceived as employer of choice
3	moderate	▪ financial loss of $____________up to $____________ ☐ national short-term negative media coverage ☐ report of breach to regulator with immediate correction to be implemented ☐ out-patient medical treatment required for employees or third parties, such as customers or vendors ☐ widespread staff morale problems and high turnover
2	minor	▪ financial loss of $____________up to $____________ ☐ national short-term negative media coverage ☐ report of breach to regulator with immediate correction to be implemented ☐ out-patient medical treatment required for employees or third parties, such as customers or vendors ☐ widespread staff morale problems and high turnover
1	incidental	▪ financial loss up to $____________ ☐ national short-term negative media coverage ☐ report of breach to regulator with immediate correction to be implemented ☐ out-patient medical treatment required for employees or third parties, such as customers or vendors ☐ widespread staff morale problems and high turnover

Table C.2: Template for risk likelihood scale from Curtis and Carey (2012)

Rating	Frequency		Probability	
	Descriptor	Definition	Descriptor	Definition
5	frequent	Up to once in_______or more	almost certain	___% or greater chance of occurrence over life of asset or project
4	likely	once in_______up to once in ________	likely	___% up to___% chance of occurrence over life of asset or project
3	possible	once in________up to once in ________	possible	___% up to___% chance of occurrence over life of asset or project
2	unlikely	once in________up to once in _________	unlikely	___% up to___% chance of occurrence over life of asset or project
1	rare	once in_________or less	rare	<___% chance of occurrence over life of asset or project

Table C.3: Template for risk vulnerability scale from Curtis and Carey (2012)

Rating	Descriptor	Definition
5	very high	☐ No scenario planning performed ☐ lack of enterprise level/process level capabilities to address risks ☐ responses not implemented ☐ no contingency or crisis management plans in place
4	high	☐ scenario planning for key strategic risks performed ☐ low enterprise level/process level capabilities to address risks ☐ responses partially implemented or not achieving control objectives ☐ some contingency or crisis management plans in place
3	medium	☐ stress testing and sensitivity analysis of scenarios performed ☐ medium enterprise level/process level capabilities to address risks ☐ responses implemented and achieving objectives most of the time ☐ most contingency and crisis management plans in place, limited rehearsals
2	low	☐ strategic options defined ☐ medium to high enterprise level/process level capabilities to address risks ☐ responses implemented and achieving objectives except under extreme conditions ☐ contingency and crisis management plans in place, some rehearsals
1	very low	☐ real options deployed to maximize flexibility ☐ high enterprise level/process level capabilities to address risks ☐ redundant response mechanisms in place and regularly tested for critical risks ☐ contingency and crisis management plans in place and rehearsed regularly

Table C.4: Template for risk velocity scale from Curtis and Carey (2012)

Rating	Descriptor	Definition
5	very high	very rapid onset, little or no warning, instantaneous
4	high	onset occurs in a matter of__________________
3	medium	onset occurs in a matter of____________
2	low	onset occurs in a matter of_____________
1	very low	very slow onset, occurs over______or more

Appendix D

Additional Enterprise Architecture Frameworks

D.1 DoDAF

DoDAF also finds it origins with the US department of defense and is an evolution of the Command, Control, Communications, Computers, and Intelligence (C4ISR) architecture framework started in 1990. DoDAF is often used for compliance with government standards and its military roots are prevalent. DoDAF, since 2009 in version 2, describes the architecture as an integration of viewpoints, see figure D.1, to provide the visualization infrastructure for specific stakeholders concerns (Department of Defense, 2010; Giachetti, 2012). Although not mandatory DoDAF version 2 now comes with a generic six-step architecture development process for creating an architectural description:

1. Determine the intended use of the architecture
2. Determine scope of architecture
3. Determine data required to support architecture development
4. Collect, organize, correlate, and store architecture data
5. Conduct analyses in support of architecture objectives
6. Document results

Similar, in purpose, to Zachman's Framework, DoDAF also does not focus on architecture development but rather on specifying the architectural artifacts themselves. DoDAF has spawned many derivative frameworks such as the NATO Architecture Framework (NAF) and the UK Ministry of Defense Architecture Framework (MODAF).

D.2 Federal Enterprise Architecture Framework

A model created by to unite US governmental agencies and functions on a common EA. The FEA segments and divides the enterprise (Sessions, 2007; Aldea, 2014). FEA with at its core the Consolidated Reference Model (CRM)provides its agencies with a framework to describe and analyze investments. It consists of interrelated reference models across six architectural domains:

1. Strategy
2. Business

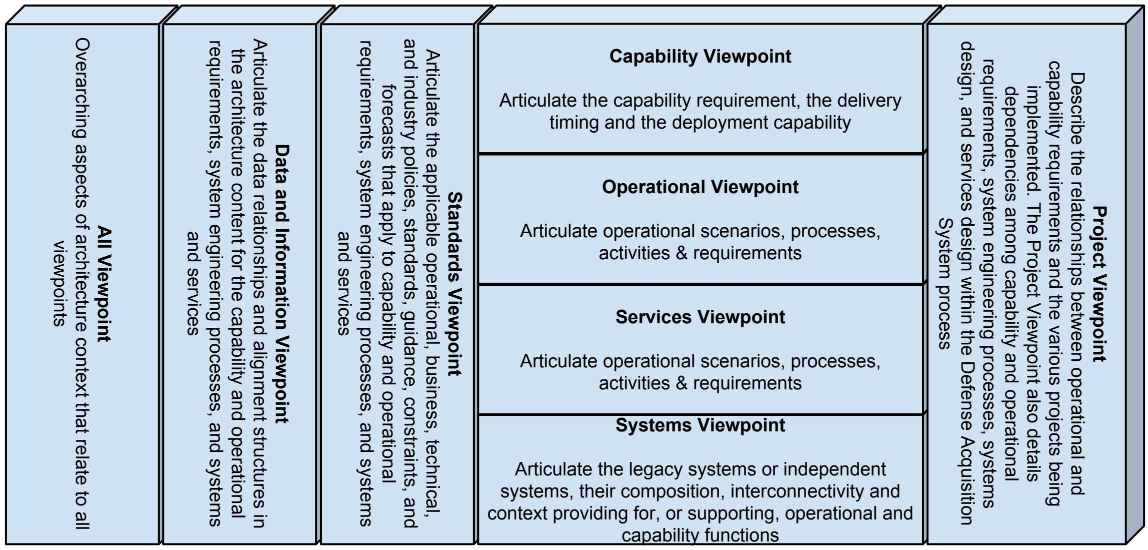

Figure D.1: DoDAF Viewpoints

3. Data
4. Applications
5. Infrastructure
6. Security

FEA provides a comprehensive taxonomy and architectural process for each of these domains in reference models and FEAF provides an architectural process that describes the enterprise lifecycle.

D.3 Gartner EA Framework

December 2004 saw the acquisition of direct rival the Meta Group by Gartner which created one of the largest IT consultancies active on EA. Gartner divides their methodology in two major components:

1. the Gartner Enterprise Architecture Process Model (GEA PM)
2. the Gartner Enterprise Architecture Framework (GEAF)

GEA PM represents key characteristics and best practices for developing and maintaining an EA, GEAF creates a common, business outcome oriented, vision between three common architectural viewpoints between the following viewpoints:

- Enterprise Business Architecture (EBA)
- Enterprise Information Architecture (EIA)
- Enterprise Technology Architecture (ETA)

The GEA PM, is a continuous, iterative, phased, and non-linear model that centers its activities around a business-oriented future state. It is focused on process development, evolution and migration, governance, organizational and management sub-processes and develops a desired future EA state before describing the current state. Gartner follows a top-down strategy to address the outcomes of a gap analysis between the future and current EA state that uses

Gartner's extensive applied research knowledge. ESAF, the Enterprise Solution Architecture Framework, describes meta-architecture and is composed of requirements, principles and models that guides enterprise and solution architects in combining and reconciling the different viewpoints into a unified architecture. ESAF also includes a log of all these decisions and reconciliations made and highlights the specific dependencies and inconsistencies among elements of the viewpoints. Overall Gartner's methodology is a practice driven framework, most documentation available online is non-descriptive, outdated (2005) and based on experience rather than academic rigor.

Appendix E

Archimate Decision Making Meta-Model

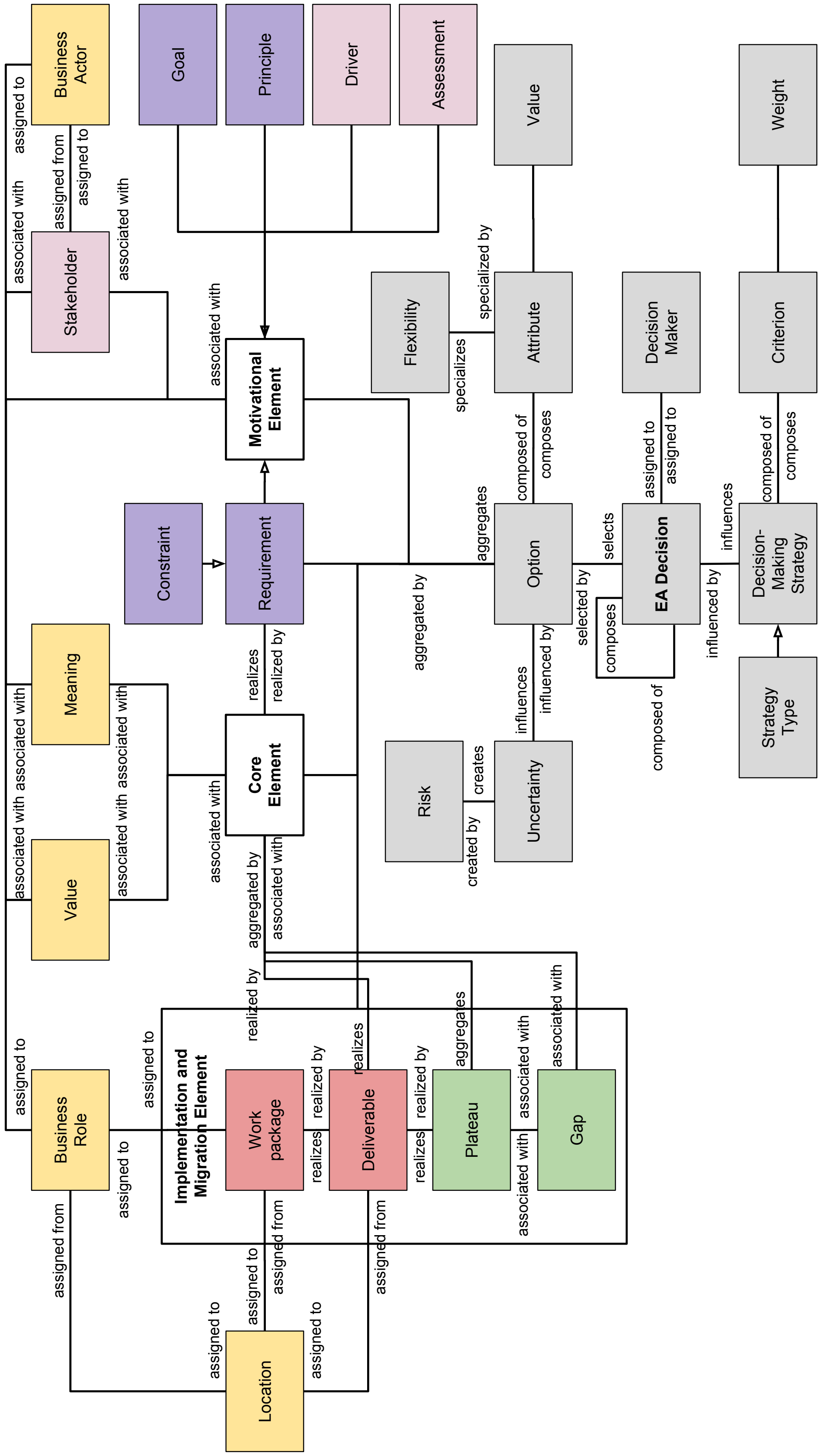

Figure E.1: Archimate Decision Making Meta-Model

Appendix F

Decision Options Modeling

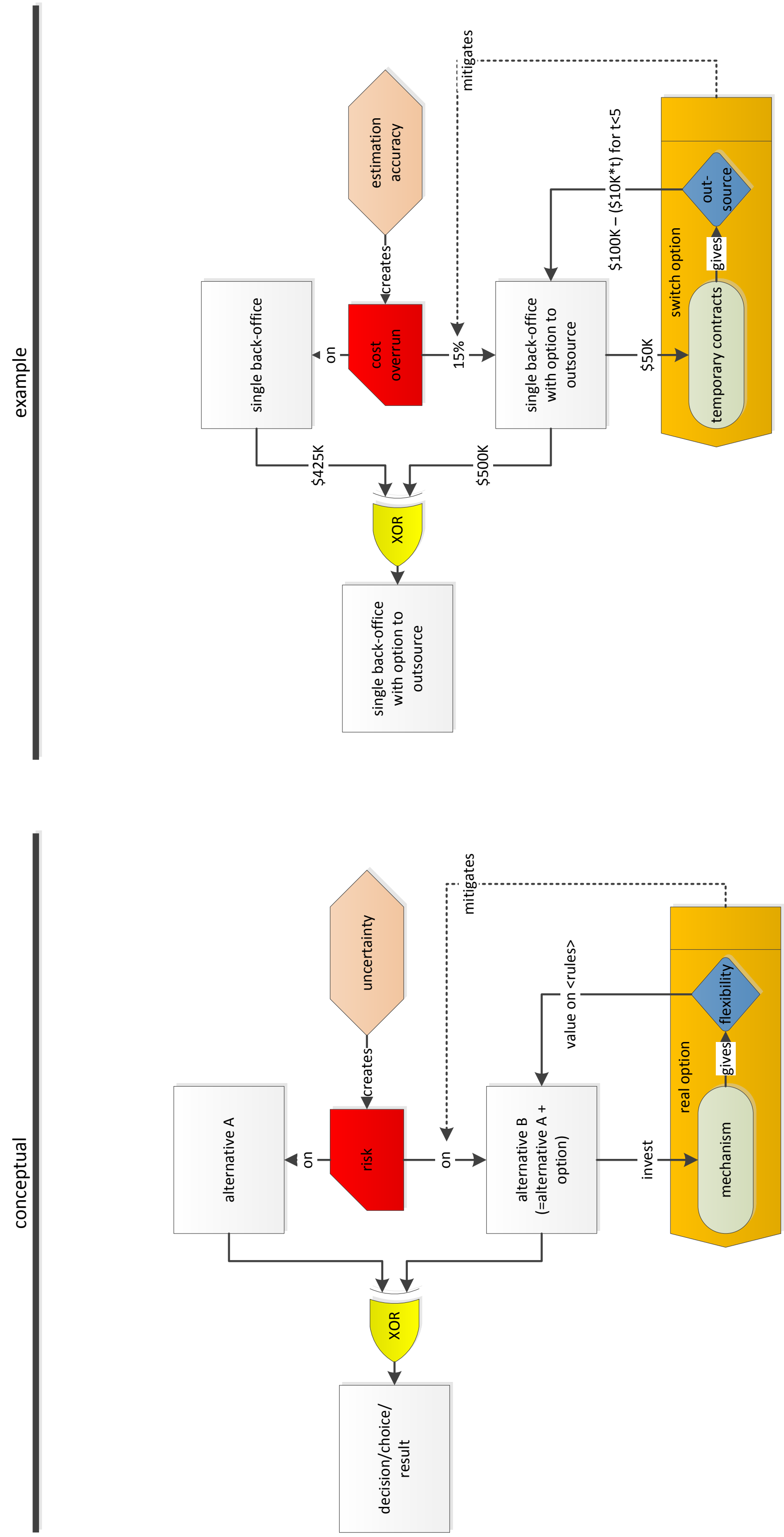

Figure F.1: Basic decision

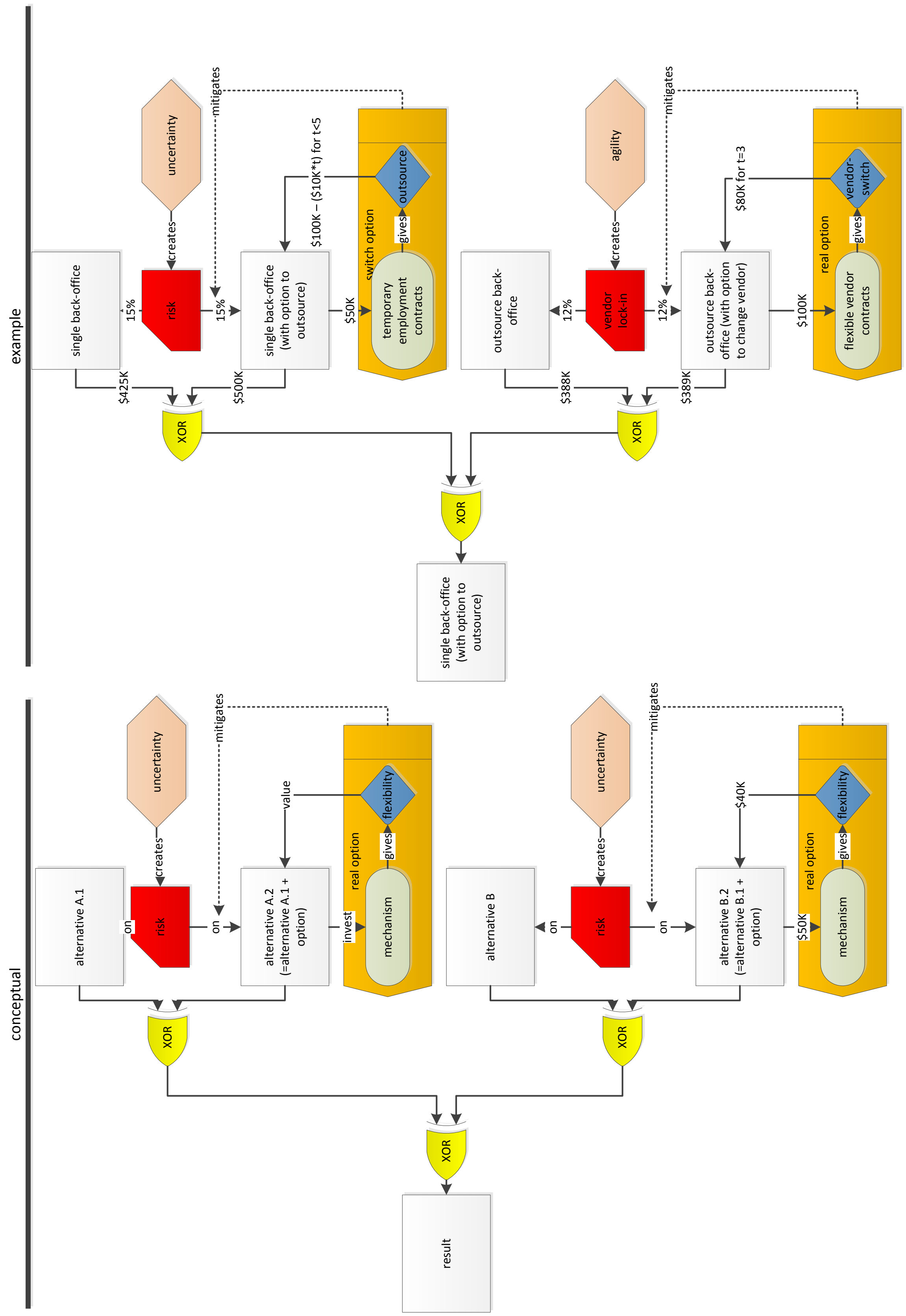

Figure F.2: Alternatives with option

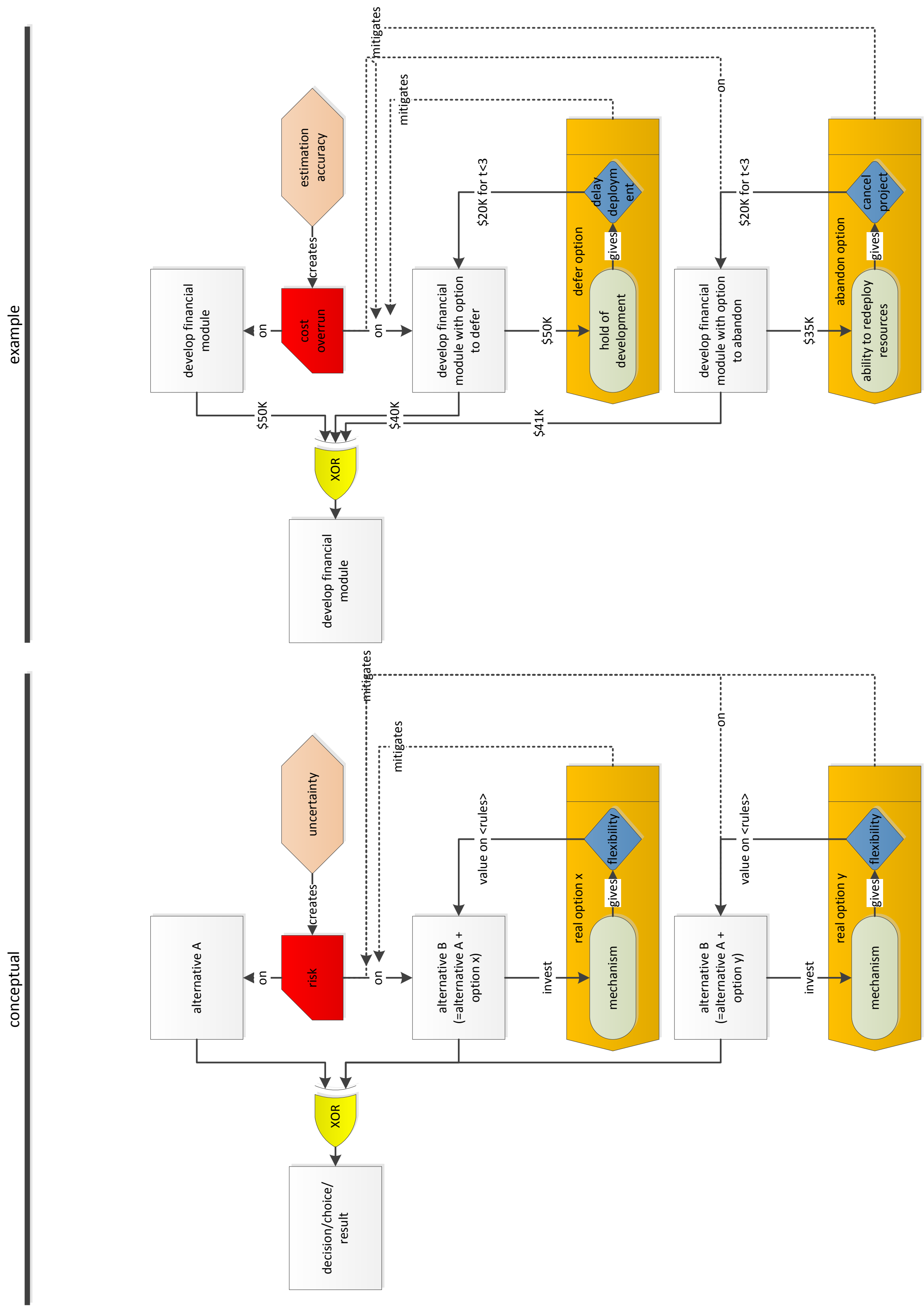

Figure F.3: Alternatives with options

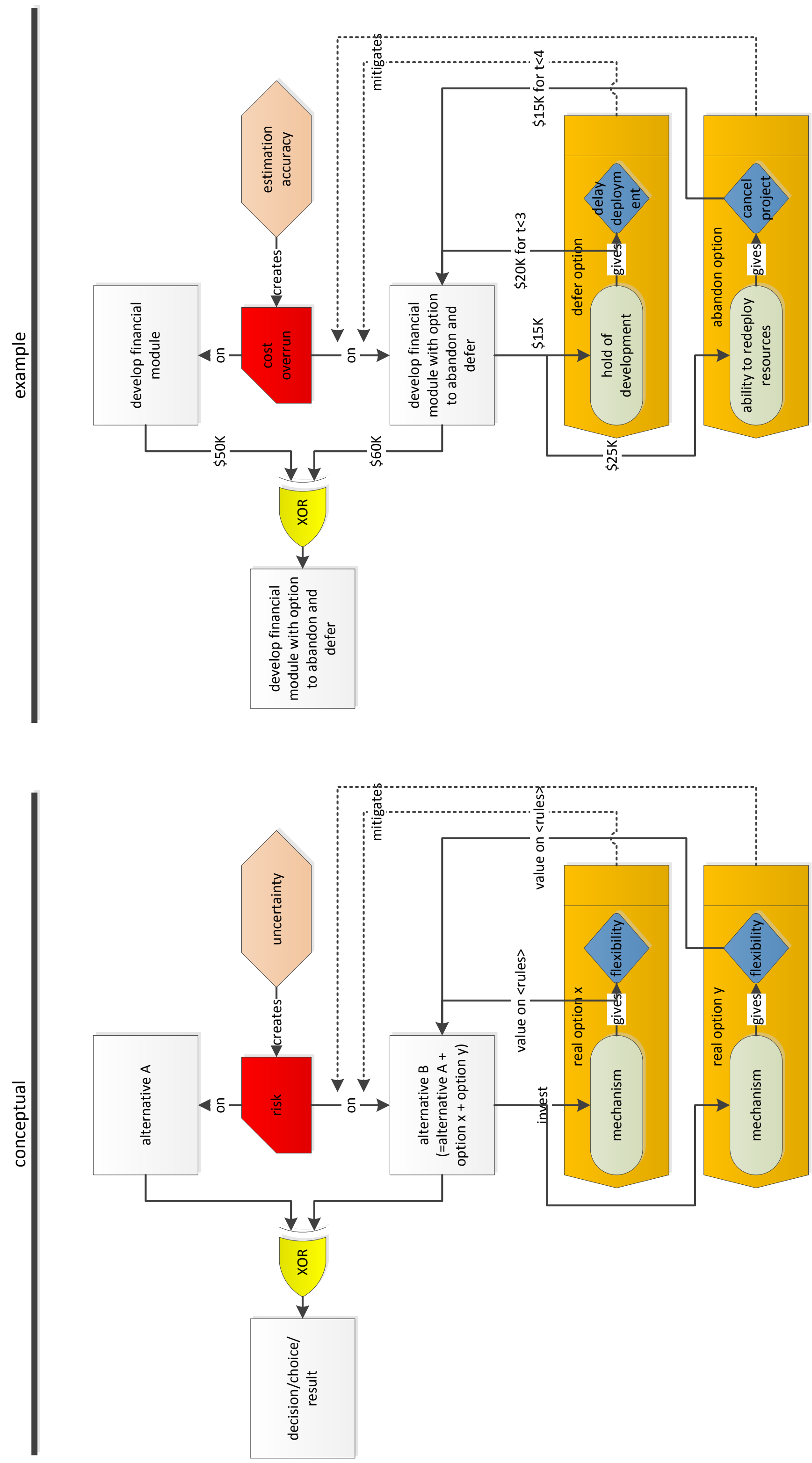

Figure F.4: Alternative with options

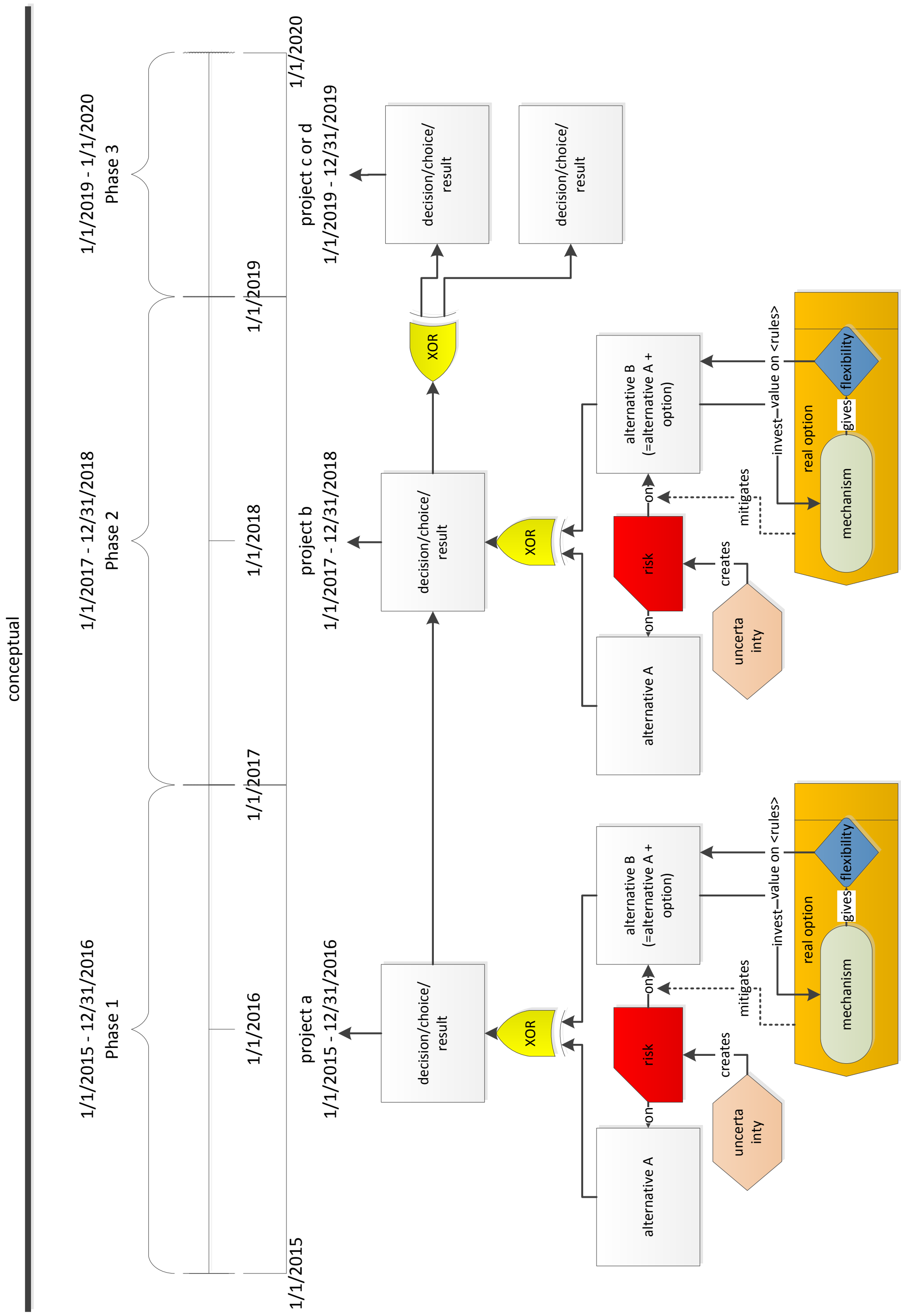

Figure F.5: Alternatives on timeline

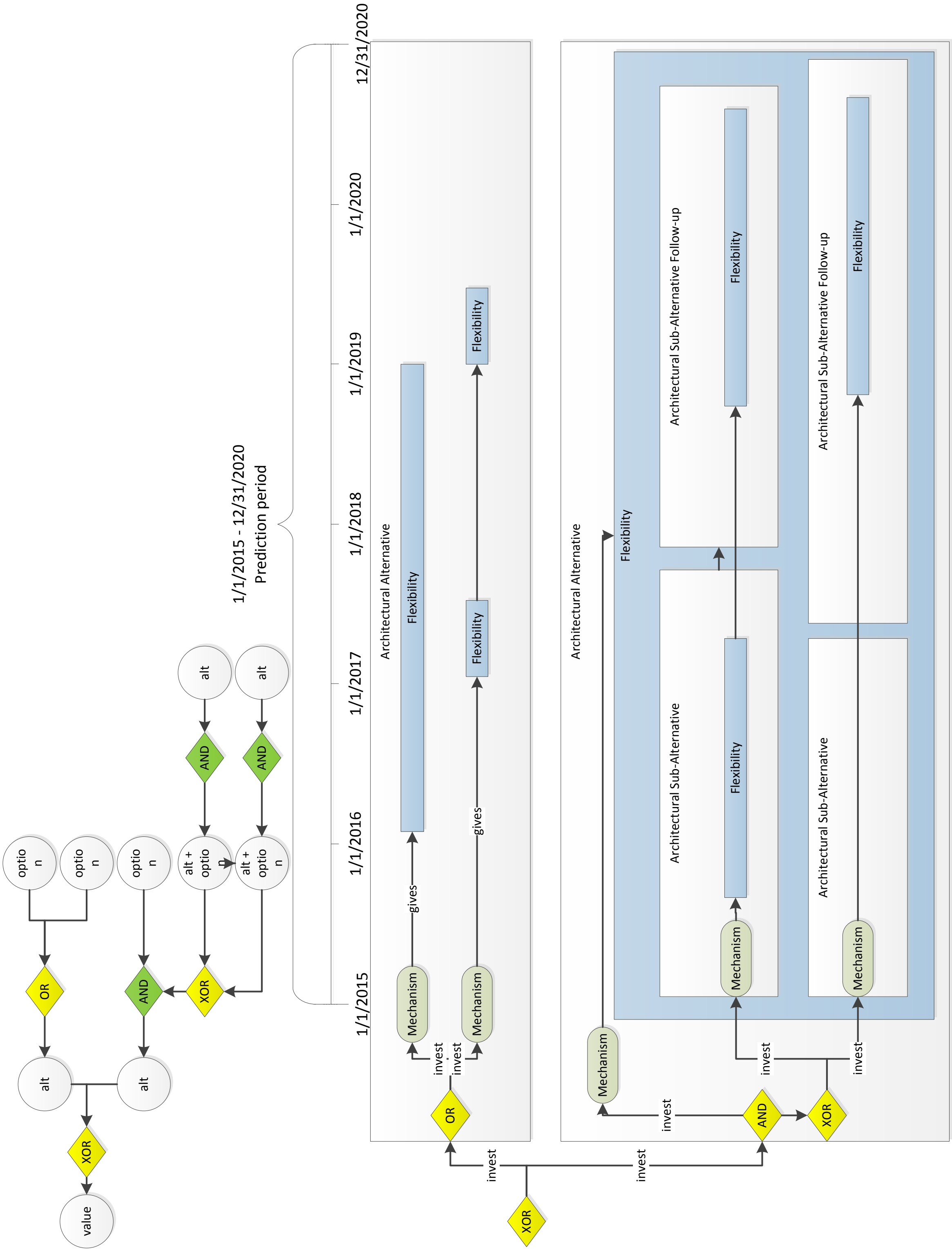

Figure F.6: Timeline with options tree conceptual

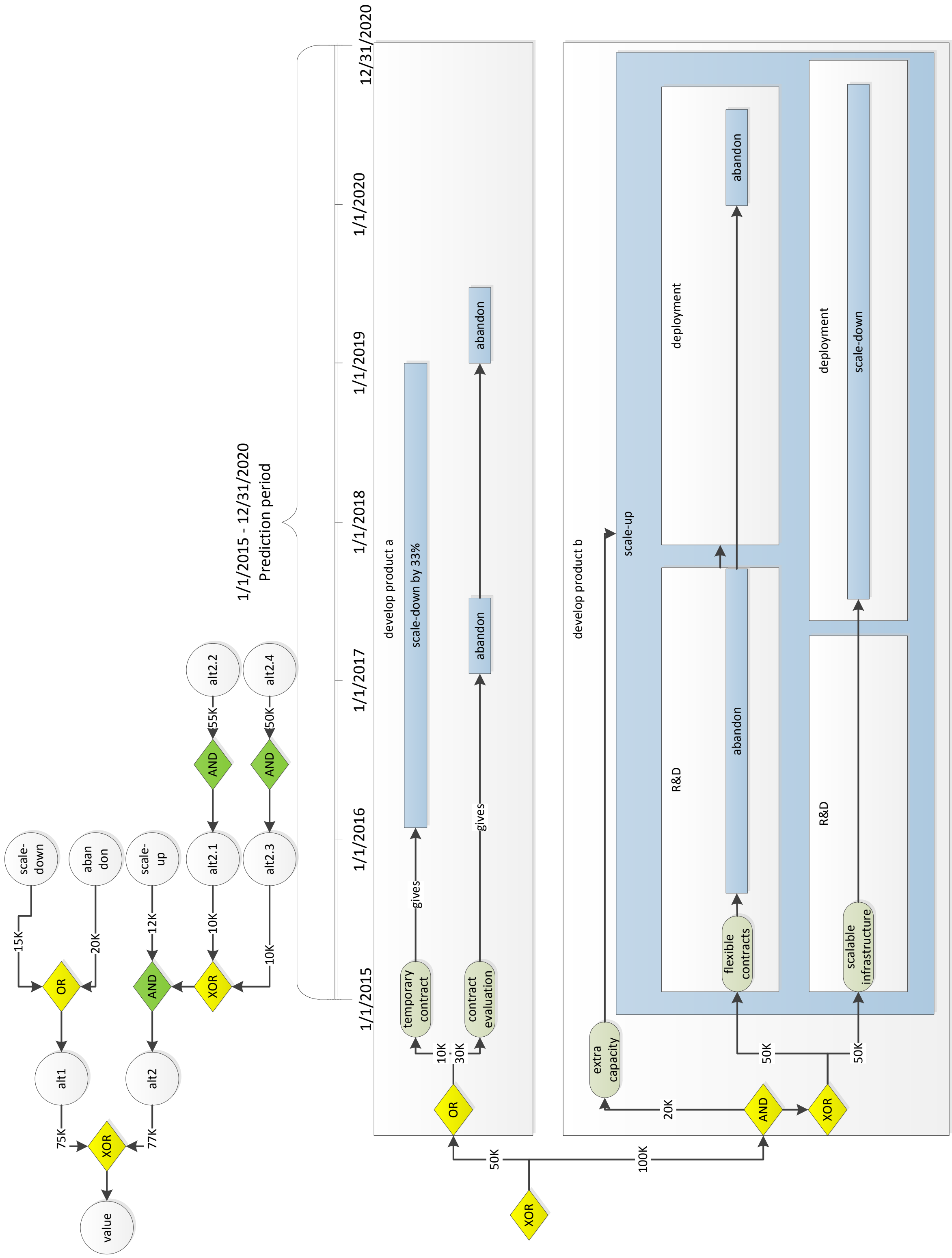

Figure F.7: Timeline with options tree example

Appendix G

Matlab Real Option example

```
Price = 120000; %asset price
Strike = 120000; %exercise price
Rate = 0.13; %risk-free rate
Time = 7; %number of periods until mature
Increment = 1; %time increment
Volatility = 0.4; %estimated volatility
Flag = 1; %call (1) or put (0)
DividendRate = 0; %optional dividend rate
Dividend = 0; %optional dividend at ex-dividend date
ExDiv = 0; %optional ex-dividend date

%real option variables
scopedown = 0.5;
savings = 75000;


[AssetPrice, OptionValue] = binprice(Price, Strike, Rate, Time, ...
                                     Increment, Volatility, Flag, ...
                                     DividendRate, Dividend, ExDiv);
disp('AssetPrice:');
disp(AssetPrice);
%filename = 'assetprice.csv';
%csvwrite(filename,AssetPrice);

disp('OptionValue:');
disp(OptionValue);
%filename = 'optionvalue.csv';
%csvwrite(filename,OptionValue);

disp('Up factor u: ');
u = exp(Volatility*sqrt(Increment));
disp(u);
disp('Down factor d: ');
d = exp(-Volatility*sqrt(Increment));
disp(d);
disp('Probability p: ');
p = (exp((Rate-Dividend)*Increment)-d)/(u-d);
disp(p);
```

```
[x,y] = size(AssetPrice);
%decision tree
dtree = zeros(x,y); %create dtree with size of bintree

%evaluate terminal node max(terminalvalue,optionvalue)
for i = 1:1:y
    if (AssetPrice(i,y) * scopedown + savings > AssetPrice(i,y))
        dtree(i,y) = AssetPrice(i,y) * scopedown + savings;
    else
        dtree(i,y) = AssetPrice(i,y);
    end
end

%backtrack through tree
col = 0;
for col = y:-1:1
  row = 1;
  while row < col
    binomialValue = (p * dtree(row, col) + (1-p) * dtree(row+1,col)) ...
                  * exp(-Rate * Increment);
    if (binomialValue > scopedown * AssetPrice(row, col-1) + savings)
      dtree(row, col-1) = (p * dtree(row, col) + (1-p) * dtree(row+1,col)) ...
                        * exp(-Rate * Increment);
    else
      dtree(row, col-1) = scopedown * AssetPrice(row, col-1) + savings;
    end
    row = row + 1;
   end
end
disp('decision tree: ');
disp(dtree);
```

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