Analysis of the tool for the valuation of R&D projects

A research conducted by Philips Lighting

Author:	Willem Chung
Student number:	s0025267
Educational Institution:	University Twente
Company:	Philips Lighting
Supervisor at the company:	Ruud Gal
Supervisors at the university:	Marc Wouters and Berend Roorda

Management Summary

Cause

At Philips Advanced Development Lighting (Philips ADL) there is a tool. This tool, which is implemented in 2006, is used for the valuation of ADL projects. However, the tool has not yet been checked on correctness. Another issue is to suggest some ways of how to improve the current tool.

Recommendations

After the analysis I have come up with three recommendations:

1. Make use of conditional chances to calculate the success chances for the different scenarios.
2. Introduce a discount rate in the predevelopment stage.
3. Improve the input parameter "estimated chance of technical success" by implementing a group process for estimating the success chances of the key uncertainties.

Motivation

When each key uncertainty of the project has influence on just one scenario, the success chance of a scenario is simply calculated by multiplying "the probability of success of all the key uncertainties which are necessary for that particular scenario" and then multiplying this success chance with the failure chances of the previous scenarios. However, in most of the situations, the key uncertainties have influence on multiple scenarios. This is the reason why conditional chances have to be used.

In the current model the cash flows of the scenarios are not discounted in the predevelopment stage, because the duration of this first stage is not known for certain. However, it improves the accuracy if the cash flows are discounted in the predevelopment stage using a risk free rate, because of the time value of money.

In the current model the project leader is the only person who estimates the success chances of the key uncertainties. Because of information asymmetry it is possible for the project leaders to manipulate these chances. By estimating the chances in a group, these manipulations will be reduced. And besides this advantage, the measurement errors will also be reduced. Finally, the members of the group could help the project leader to define the most important key uncertainties of the project. The pilot study showed that the group approach is very useful.

Consequences

The implementation of these recommendations will make the tool more accurate.

Preface

This report is the final result of my graduation assignment of the study Industrial Engineering & Management (in Dutch Technische Bedrijfskunde) at the University of Twente, The Netherlands. I would like to thank Philips for giving me the opportunity to do this assignment at their company. I would like to thank all the people in the company for their support, especially Ruud Gal. I also want to thank my two tutors of the University, Marc Wouters and Berend Roorda, for helping me through this assignment.

Chapter 1 Introduction

1.1 Introduction

This chapter describes the organisation and the current tool. In paragraph 1.2 the organisation will be described. In that part, three examples of different projects will be given to give a better view of the organisation. In paragraph 1.3, the current tool will be briefly introduced. In chapter 3 this tool will be described in more detail. In paragraph 1.4 the sequence of solving the key uncertainties are discussed. Although the current tool is not used to determine which key uncertainties should be solved first, this is an important issue within the organisation. In paragraph 1.5 the problem definition and the research questions are formulated.

1.2 Description of the organisation

This thesis is conducted for Philips ADL (Advanced Development Lighting). Advanced Development Lighting is the pre-development organization, based in Eindhoven. The organisation has approximately 250 employees. The focus of ADL is on the predevelopment of new products. The products of ADL can be classified into three categories, namely Discharge & Filament (the "normal" lamps), Solid State Lighting (for example the LEDS) and the New Value Drivers (the lamps, which are not used for lighting the environment, but the lamps that are used for decoration for instance).

The task of ADL is to invent and develop new products, which have a real application for the consumer. The direct customers of ADL are the different business groups within Philips Lighting (Automotive, Special Lighting Applications, Lamps, Lighting Electronics, Solid State Lighting, Lumileds and Luminaries). ADL is divided into 4 different departments (Materials & Processing, Discharge Lamps, Electronics and Systems) with each department focussing on at least one of the business groups. See the organisational chart of ADL in figure 1.
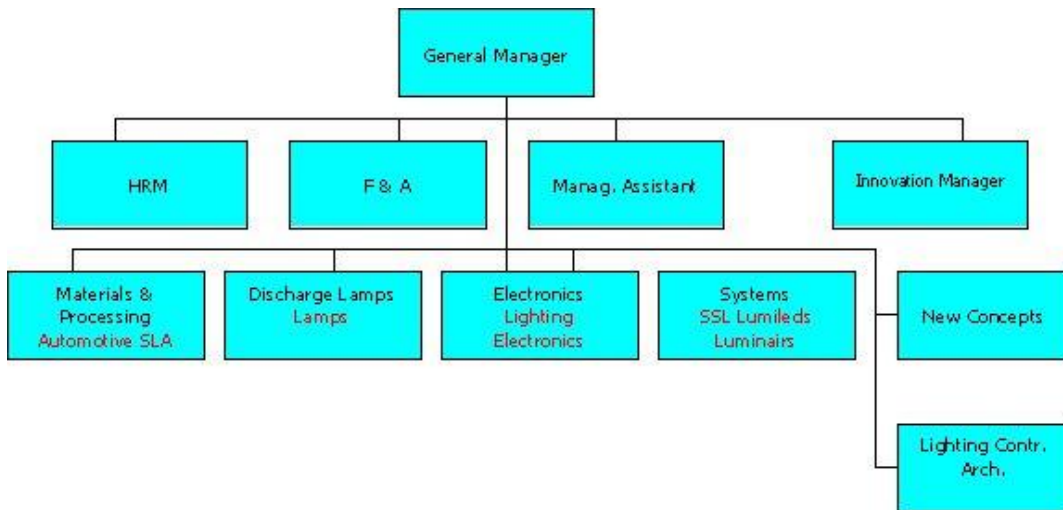
Figure 1, organisational chart of ADL.

In the predevelopment stage the organization has to deal with many sorts of uncertainties. There are two groups of uncertainties which can be separated, technical uncertainties and the non-technical uncertainties. The technical uncertainties define all the technical deliverables which are needed for the technical accomplishment of the project. The non-technical uncertainties are for example the commercial acceptability of the project, but also the capability of the supplier to deliver the right quality. The chance that a competitor is faster with a solution is also an example of an non-technical uncertainty. Sometimes a project can only proceed when another project fails, this uncertainty is also an example of a non-technical uncertainty. In the next part, three examples of projects will be given to give a better view of these uncertainties. For ADL, all these uncertainties are equally important (the weights of all the uncertainties in the tool are the same), but the focus of ADL is on the technological uncertainties. This is caused by the fact that in the predevelopment stage the technological uncertainties are the only uncertainties, which can be directly influenced by the ADL. By allocating FTES (full time equivalents) to the project, technological uncertainties can be eliminated or reduced.

Each project is going through some milestones. See figure 2.

Figure 2, milestones.

Milestone –3 = Start concept creation

Milestone –2 = Concept proven

Milestone –1= Start platform development

Milestone 0 = Global platform defined

The technological people do a lot of knowledge development, but this is not the starting point of milestone -3. Only when the knowledge has a real application, milestone -3 is starting. In this milestone the project leader and his team define the key uncertainties of the project. I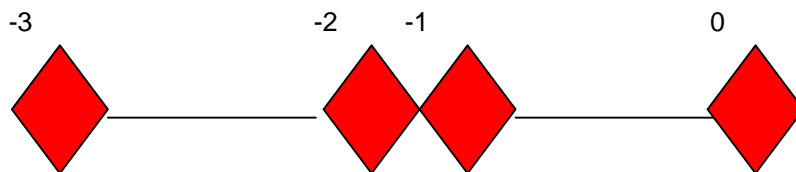f the concept of the project is proven, the project team will start with the production platform development. After the production platform is defined, ADL will transfer the project. At this point, ADL is not responsible anymore for the project. The value of the project is cashed in, in this phase. Even if the project is not a commercial success, the value cashed in will not be adjusted.

In the next part, three examples of projects are given to get a better view of the organisation. Project B is lef tout because of confidentiality.

Project A:

This is a project where light is being used to treat acne. All the key deliverables which are needed to make this product technical feasible is a form of a technical uncertainty. The chance that this anti-acne system is technical so successful, which makes outperformance of all the current alternatives possible (like for example skin cremes), is also a form of a technical uncertainty. Besides these technical uncertainties there are also other uncertainties which are needed to be solved. To make it possible to bring this product into the market, it is necessary that Philips Healthcare does want this product in their portfolio. If not, the project has to be abandoned. This sort of uncertainty is a form of a non-technical uncertainty. Another uncertainty is the commercial acceptability of the product. To become a commercial success, this product has to be accepted by the end consumers.

Project C:

This is a project where a special light is used in a television. The chance to deliver the quality of light that is high enough for the television is a technical key uncertainty. Another technical key uncertainty is that a special phospor is needed for this television. The success chance that this phospor can be created is a technical deliverable. A commercial uncertainty of this project is the acceptance of the quality of the color delivered by the lamps. Another non-technical uncertainty is that the cost price of the product has to be kept low, although there are many internal profit centres in the chain of this product.

1.3 Reason new tool

Determining the financial value of a project is very difficult, especially in the predevelopment stage. This is caused by the fact that in this stage there is a lot of technology and market uncertainty. Technology and market uncertainties change the viability of the new product, so the value of new projects is frequently adjusted during the predevelopment stage. A project could lose its total value when a technology does not work as expected. On the other side, a project might strongly increase in value when there is a technology breakthrough. Beside these technology uncertainties, market uncertainties like the market demand and competition have influence on the value of the project. All these different sorts of uncertainties make the use of the standard discounted cash flow method not suited. Multiple scenarios have to be taken into account.

It is important to keep track of the value of a project, because the value of a project determines the FTES that is getting allocated. This is the reason why ADL is started to use a model that is called the option model. The implementation of this new tool started in April 2006. This tool is used as a project portfolio tool. It is used to compare projects with each other. The model is capable to follow the value of a project by using decision trees. The inputs in this model are the key deliverables (key uncertainties), the different scenarios (a scenario with a lower NPV than another scenario will only count when the other scenario fails) with the NPV per scenario and the success probability of each key deliverable. The project leader and his team determine the key deliverables, the possible scenarios and the success probabilities of the key deliverables. The calculation of the NPV of the different scenarios is done by the project leader together with the product manager (the commercial man from the business groups). Each scenario requires at least one key deliverable. By multiplying the chance of success with the NPV of the scenario the option value of the overall project is determined.

In example 1 a very simplified example is given. In this example it is assumed that each key uncertainty has just influence on one scenario. When this is not the case, the formula is more complicated. This will be discussed in paragraph 4.1.

In Appendix A the lay out of the real model is given. In the next chapter the model will be explained in more detail.

Example 1

	Scenario 1	Scenario 2	Scenario 3
NPV	100	80	60

	Estimated probability of success (Current Date)		Estimated probability of success (3 months from now on)				
Key deliverable							
A	0,6		0,8		1		
B	0,75		0,8			1	
C	0,8		0,95				1
D	0,6		0,65			1	

	Scenario 1	Scenario 2	Scenario 3
Probability per Scenario	60,00%	18,00%	17,60%

Figure 3, summary example of a project.

The "1" means that the key deliverable is required for the scenario.

The probability of scenario 1 is the success chance of key uncertainty A, 60%.

Scenario 2 will only counts when scenario 1 fails. The probability of scenario 2 is the failure chance of scenario 1 (40%) * 0.75 * 0.6 = 18%.

The probability of scenario 3 is 17.6% (when scenario 1 and 2 both fail).

The value of this project is 0.6 * 100 + 0.18 * 80 + 0.176 * 60 = 84.96.

1.4 Determining the sequence of solving the key uncertainties

There is the problem to determine which key uncertainties should be solved first, because there are more FTES needed for the projects than available. This means that methods have to be developed to work as efficient as possible. The tool is currently used as a project portfolio tool, but this tool can also be used as a tool to discuss with the project leader to determine which key uncertainties to focus on, the sequence in which the different uncertainties should be solved first.

Sometimes it is better to solve thee uncertainties in parallel and in other cases in serial is preferable. The advantage of working in parallel is that the results of the key uncertainties will be got sooner than working in serial. However, the costs involved are also higher. Working in serial has the advantage that the costs involved are lower, because when it is certain that one key uncertainty is failing for sure, the solving of some key uncertainties is useless, because that particular scenario will fail. The disadvantage of this method is that the results will be obtained later. For example, a lamp has to achieve a high temperature to generate more light. The problem with this high temperature is that there is the possibility of "hanging wires" during the lifetime. So this problem has to be solved. Suppose that there is also another technical uncertainty, the key uncertainty of not possible to close the tube. When the problem of hanging wires can be solved, but the tube could not be closed due to the solution, it makes no sense to work parallel on these two key uncertainties. However, for some projects there is a time penalty. If the project is not being brought into the market within a time period, the project will be cancelled because competitors have made the first move.

There are different methods to determine the sequence. One of them is using linear programming. With linear programming it is possible to determine which key uncertainties have the highest contribution to the option value. To determine this, some variables have to be added into the model first, namely the FTES needed per key uncertainty and the time necessary to solve the key uncertainties. Another method could be solving these key uncertainties with the lowest success chances first. If these uncertainties could not be successful, it is for sure that at least one scenario will fail. Then it makes no sense to put FTES in the other uncertainties which are necessary for that particular scenario.

1.5 Problem definition and research questions

There are still some issues to be resolved. The model has not yet been checked on correctness. This is important, because the value of the project determines the importance of the project and thus the FTES that is getting allocated. Another issue is the information asymmetry. Because of information

asymmetry (the project leader has more information about the project than the innovation manager) it is possible for the project leader to manipulate these chances. Sometimes it is necessary for a project leader to be more optimistic to get a higher chance of acceptance for the project and in some cases the project leader will me more cautious in making the estimates to insure himself against potential failure of the project. This gives the following problem definition:

Problem definition

Is the financial value of the projects calculated with the current model, which is based on the real options theory, valid?

To answer this problem definition the following research questions have been formulated:

Research questions

- Which are the most important characteristics of Real Options for the valuation of R&D products?
- Is the current model, which is based on Real Options theory, correct?
- Which improvements are needed for the current tool?
- Which methods could be used to improve the input parameter estimated chance of technical success?
- Is the method applicable for ADL?

To answer the research questions "Which are the most important characteristics of Real Options for the valuation of R&D products?" and "Which methods could be used to improve the input parameter estimated chance of technical success?" a literature study is used. To answer the research questions "Is the current model, which is based on the Real Options theory, correctly?" and "Which improvements are needed for the current tool?" the literature obtained is compared with an analysis of the current tool. To answer of "Is the method applicable for ADL?" a pilot study is conducted.

Chapter 2 The Context

2.1 Introduction

In the past, the value of projects was calculated using the discounted cash flow method. Under this approach the estimated future cash flow from an investment project are discounted to their present value using the opportunity cost of capital (Brealey and Myers, 2002). There were also multiple scenarios, but the probability of each scenario was just a rough estimation of the project leader and the customer relation manager (CRM, the head of the departments). However, the projects were not selected based on their NPV, it was the instinct the CRM had for the opportunity the project would create. ADL also made (and still make) use of the programme PCS 4 / PCS 5. PCS stands for Portfolio Characterization System. The tool gives an overview of four different main factors, namely the technical success score, commercial success score, the strategic attractiveness score and the market attractiveness score. The scores of the main factors are calculated by the scores of their sub factors. Each main factor has its own sub factors. There are around 60 different sub factors. Examples of some sub factors are for instance the technological competitive position, technological competitive impact, the technical breakthrough, the market size, the market share etc. For each of these sub factors a score is given (a number between the one and five, where five is the highest score and one the lowest) by the project leader and the product manager (the commercial man). The project leader is responsible for the technical part and the product manager for the commercial scores. The scores for the main factors are then computed by the scores of these sub factors, where each sub factor has the same weight (see also example 2).

Example 2 Calculation of the scores of the main factors:

Main factor 1 (Technical success score):

Score Sub factor 1.1 = 2
Score Sub factor 1.2 = 3
Score Sub factor 1.3 = 5
Total score = 10, Average score= 3.33

Main factor 2 (Commercial success score)

Score Sub factor 2.1 = 1

Score Sub factor 2.2 = 2

Score Sub factor 2.3 = 3

Total score = 6, Average score= 2

Main factor 3 (Strategic attractiveness score)

Score Sub factor 3.1 = 4

Score Sub factor 3.2 = 2

Score Sub factor 3.3 = 4

Total score = 10, Average score= 3.33

Main factor 4 (Market attractiveness score)

Score Sub factor 4.1 = 5

Score Sub factor 4.2 = 4

Score Sub factor 4.3 = 3

Total score = 12, Average score= 4

However, the tool has some disadvantages which makes it not capable to use as a project portfolio tool. Below the disadvantages of the PCS tool will be described in more detail.

The first disadvantage is it does not consider multiple scenarios of a project. In most of the cases a project has multiple sub products. If the core product can not be a technical success, another product may be produced. These scenarios are left out in the PCS tool, which means it underestimates the value of the total project. The second disadvantage of this programme is that it views the projects independent from each other. The tool is a project-by-project tool. In some cases a project could only proceed when another project fails. These correlations between projects are not considered in the PCS 5 tool. Suppose there are 5 different projects: project A has a value of 20 million, B 15 million, C 25 million, D 50 million and E 10 million. When the management wants a total project portfolio value of for example 60 million, the management will select the projects A, B and C (or the projects D and E, depending on the FTES needed per project and the availability of FTES). But when project B could only proceed when project A fails, the value of the portfolio calculated is too optimistic. The portfolio value then is only 45 million and not 60 million. The third disadvantage of the tool is that there are a lot of sub factors. The project leader and the product manager can always find some sub factors which is in favour of their project. These sub factors makes it complicated to compare the projects with each other. Another disadvantage of the PCS tool is there is not one score which makes it possible to compare the projects with each other. Using the mean score of the four different main

factors is not really a good method, because in this case it is possible to compensate a low score on one main factor with a high score on another main factor. These disadvantages were one of the reasons why the new tool was introduced in April 2006. Another reason was that the management wanted a tool, which could help them to compare the projects and to make decisions (for example, in which projects should the FTES be put).

The customer relation managers of the different departments decide which projects are considered for an analysis with the tool. Each department has multiple projects available, but the customer relation manager starts with filtering out the projects to select the most valuable projects. After that, these projects will be sent to the innovation manager who will analyse the project together with the project leader in more detail with the tool.

2.2 Comparison of projects

The figures 4, 5, 6 and 7 are left out because of confidentiality.

The new tool is used as a project portfolio tool. Because there are more projects, which means there are more FTES needed than available (even after the filtering by the customer relation managers), the different projects have to be compared with each other to select the best projects to invest in. The tool gives a summary of the most important risks (the key uncertainties) and the associated probabilities of success of each key uncertainty. Together with the NPV of the different scenarios it makes it possible to calculate the expected option value of the project. Besides the success chances on the current date, the success chances of the key uncertainties, assuming everything goes perfect, three months from now on is also estimated. So the target option value of a project can also be calculated (it may be that the target option value is not a good indicator, because for some key uncertainties it takes a half year to get results). This target option value and the option value per project, together with the FTES needed per project, can be used to compare the projects. See figure 4.

2.3 Development option value of a project

In figure 5 the development of the option value per project is depicted. When there is enough data, a specific trend may be discovered. This information could then, for example, be used to determine when it is necessary to reduce some FTES within the projects. At this moment, when the FTES are allocated to the project, these are held almost constantly for the duration of the project. But when the option value does not increase for a long period, it is better sometimes to decrease the FTES on one project and allocate it to another project. In figure 6 the development of the option value per project

category is depicted. This information makes it possible to compare the different categories of projects. Questions like which categories of projects contribute the most to the portfolio can be answered.

2.4 The measurement of the option value in the pipeline

The tool could also be used to determine if ADL does have enough option value in the "pipeline". Enough means the contribution to the turnover of Philips Lighting. Philips Lighting has its growth ambitions. This means it will set a target option that should be originated from the ADL. The option value in the portfolio is compared with this target option value. The "pipeline" is defined as the different milestones in the project. Each project is going through these milestones. See also figure 2, paragraph 1.2.

As mentioned before in the introduction there are three categories of projects distinguished, namely Discharge & Filament (the "normal" lamps), Solid State Lighting (for example the LEDS) and the New Value Drivers (the lamps that are not used for the lightening of the environment. For example, the lamps which are used for decoration). By measuring the time projects stayed in the different milestones, the average staying time of the three categories of projects can be estimated (I tried to look up this data with the use of some older projects. Unfortunately this data was not available).

In figure 7 the option value in the different milestones is shown.

When information is known about the average staying time of the three types of projects in the different milestones, this information together with the option value in the milestones can be used to determine if ADL is doing enough to contribute to the growth ambition of Philips Lighting.

The current tool is being used as a portfolio tool by the management and not as a project-planning tool by the project leaders. As mentioned before, the tool gives a summary of the most important risks of the project. In reality there are more risks, but these are not considered in calculating the expected option value. The project leaders have their own project-planning tool. They set up their own programmes. Each programme has a different sequence in which the uncertainties are going to be solved first.

Chapter 3 Conceptual Description of the current tool

3.1 Introduction

In this chapter the research question "Which are the most important characteristics of Real Options for the valuation of R&D products?" will be answered. This chapter discusses the theory of Real Options and some theory about the Discount Rate. In the next chapter, the application of the theory takes place.

3.2 Decision tree of the model

A decision tree is a method of representing alternative sequential decisions and the possible outcome from these decisions (Brealy and Myers, 2002). With the use of decision tree the model of ADL will be described in more detail. In figure 8 you can see the decision tree of Philips ADL.

Predevelopment   **Outcome**   **Go**

p_1 NPV1

Go $p_2 * (1-p_1)$ **Go**   NPV2   **Quit**

$p_3 * (1-p_2) * (1-p_1)$ **Go**   NPV3   **Quit**
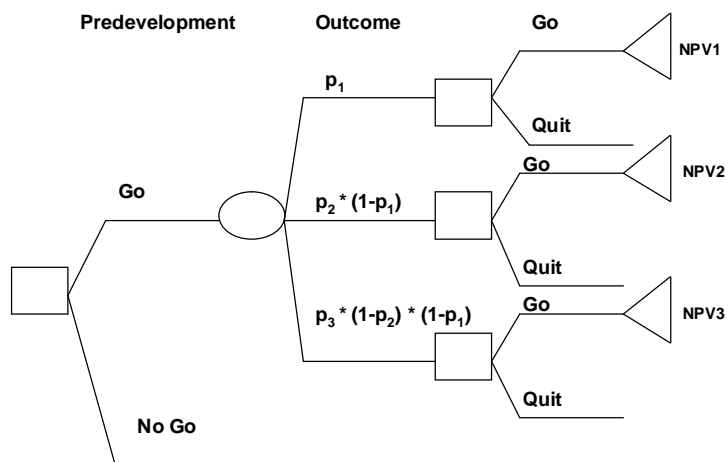
No Go   **Quit**

Figure 8, Decision tree Philips ADL

The square nodes in the figure stand for decision nodes. The circle in the figure stands for an uncertainty or event node and the triangles stand for end nodes. The first square in the figure implicates the decision whether or not to invest in the project. The organisation can choose between putting FTES in the project or not. When the organisation chooses to put FTES in the project, the first GO decision, the possible outcomes of the project are the Net Present Value (NPV) of each possible scenario. The NPV is the present value of an investment's future net cash flows minus the initial investment. This initial investment is excluding the costs of the FTES and other costs in the predevelopment stage. If the PV of a particular scenario is higher than the investment (which means the NPV is positive), the scenario will be counted in calculating the value of the project. In the scenarios where the NPV is negative, the management has the ability to abandon (to quit) these bad scenarios (real options thinking). So in the scenarios where the NPV is negative, the scenarios will not be counted in the valuation of the project.

The inputs in the model are the key deliverables (key uncertainties), the different scenarios with the NPV per scenario and the success probability of each key deliverable. The scenarios are ranked in order by the NPV of the scenario. The focus is always on the scenario with the highest NPV, which is called scenario 1. The scenario with the second highest NPV is called scenario 2, etc. Only if scenario 1 fails, scenario 2 will count. Scenario 3 will only count when scenario 1 and scenario 2 both fail etc. Each scenario requires at least one key deliverable. By multiplying the chance of success of the scenario with the NPV of the scenario and adding all these scenarios, the value of the overall project is determined.

Value project = $p_1 * NPV_1 + p_2 * (1- p_1) * NPV_2 + p_3 * (1-p_2) * (1- p_1) * NPV_3 + \ldots + p_x * (1-p_{x-1}) * (1-p_{x-2}) * \ldots * (1-p_1) * NPV_x$

p_x = The feasibility of scenario x. The chance that the key uncertainties for scenario x are all successfully resolved.

NPV_x = Net present value of scenario x

This formula was used by Philips ADL to value the different projects. However, the formula is not entirely correct. It contains some errors. In the next chapter, in paragraph 4.1, the reason why this formula is incorrect will be explained and a method to improve this formula will be discussed.

Theoretical part

3.3 Real Options

A real option is the right, but not the obligation, to take an action (for example deferring, expanding, abandoning) on an underlying non-financial asset at a predetermined cost called the exercise price for a predetermined period of time (Copeland and Antikarov, 2003). Real Options theory is used to value the flexibility of the management to act in the future. The uncertainty of the future and the flexibility of the management to respond to this uncertainty, gives a value which is not considered in the traditional valuation methods like the NPV method. These traditional methods overlook the flexibility of the management to alter the course of a project in response to changing conditions. Projects are assumed to proceed as planned, regardless of future events. Traditional valuations methods assume that the management does not move away from its plan, even if things develop differently than expected. So the management makes an irreversible decision based on its current view of the future. The project duration is assumed to be fixed, and the possibility of for example abandoning the project in the face to unexpected demand is not considered (Copeland and Keenan, 1998).

In the real options literature related to R&D, investing in the R&D stage could be seen as an initial investment which opens markets for the introduction of new products or technologies (Lint, 2000). Investing in the R&D stage creates the right, but not the obligation, to make a further investment in the next stage. At some time later, when more information is known, the next stage occurs when the organization has to decide whether or not to make a larger investment in the project. During the R&D phase, the management will often evaluate the project to consider whether the project is still worth funding. When the conditions develop favourably, the organization will decide to make some follow-on investment, but if developments are unfavourable, the follow-on investment will not be made. Traditional NPV calculations overlooked this flexibility of the management to alter the course of a project in response to changing conditions. It assumes that the management makes a permanent decision based on its current view of the future.

The value of real options is based on the assumption that there is an underlying source of uncertainty, such as the price of a commodity or the outcome of a research project. Over time, the outcome of the underlying uncertainty will be revealed and the managers can adjust their strategy accordingly. The value of an option increases when the uncertainty of the payoff increases. This is caused by the fact that the downside losses are limited by the option and there is the possibility of achieving a large upside gain (Van Putten and MacMillan, 2004). The bigger the range of possible

outcomes of the underlying asset value, the higher the option value. The uncertainty of the underlying asset is represented with the binomial tree. In the next paragraph the binomial tree will be discussed.

3.4 Introduction Binomial tree

The binomial tree gives the distribution of all the possible values of the underlying asset (Kodukala and Papudesu, 2006), but first I will give a simple example where only two scenarios are included. After this example, the valuation of a project with a range of possible outcomes is discussed.

Example 3
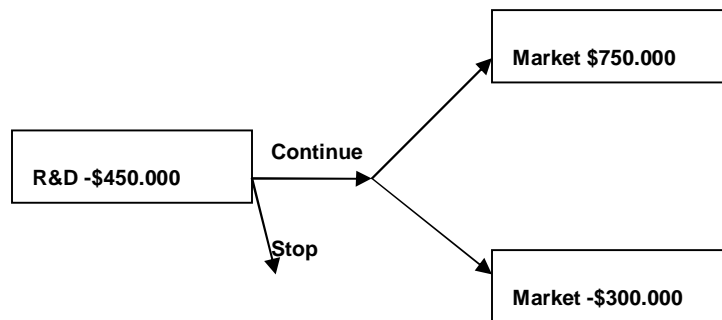
Figure 9, Summary example 3

A company has the opportunity to invest in a R&D project. After this investment, the company can choose to commercialise the project or abandon the project. Before the R&D project is carried out, it is uncertain how much the value of marketing the product will be, but two scenarios are estimated (see figure 9). The expected value of the whole project without considering the option to abandon would be - 450.000 + 80% * 750.000 + 20% * -300.000 = 90.000.

Real Options Analysis will value the whole project differently. After the R&D project, it will be known which of the two scenarios materializes.

- Suppose the first scenario materializes, then it is rational to continue, because the marginal value is positive. Hence, a total value is realized of -450.000 +750.000 = 300.000.

- Suppose the second scenario materializes, however, is rational to stop, because the marginal value of continuation is negative; -300.000. Hence, stopping limits the total loss to minus 450.000.

Real options thinking would value the whole project as -450.000 + 80% * 750.000 + 20% * 0 = 150.000. Hence, the option to abandon the project is worth 150.000 – 90.000 = 60.000.

In the example above only two scenarios are included, but in reality there is a range of possible outcomes/scenarios. The binomial tree gives an overview of this distribution of possible values of the underlying asset. The range depends on the volatility of the underlying asset. The starting point of the binomial tree is the value of the underlying asset which is calculated with the standard discounted cash flow method (The cash flows of the underlying asset are discounted by using an appropriate discount rate. In paragraph 3.8, this discount rate will be discussed). For building the binomial tree, the volatility of the underlying asset needs to be estimated. This volatility determines the size of *u* and *d*. At the start of the tree, the asset value either goes up or down and from there it continues to go either up or down in the next nodes. The up movement is represented by *u* and the down movement is represented by *d*, where *d = 1/u*. See figure 10. To calculate *u* and *d*, the following formulas are used:

- *u = exponential (volatility * square (delta t)) and*
- *d= 1/u.*

The last nodes at the end of the binomial tree give the possible value of the underlying asset at the end of the option life. In the form of a frequency histogram these asset values can be represented. Each histogram is the outcome of a single asset value and the height of the histogram represents the number of times that outcome will result through all possible paths on the binomial tree. See figure 10.

University of Twente
Enschede - The Netherlands
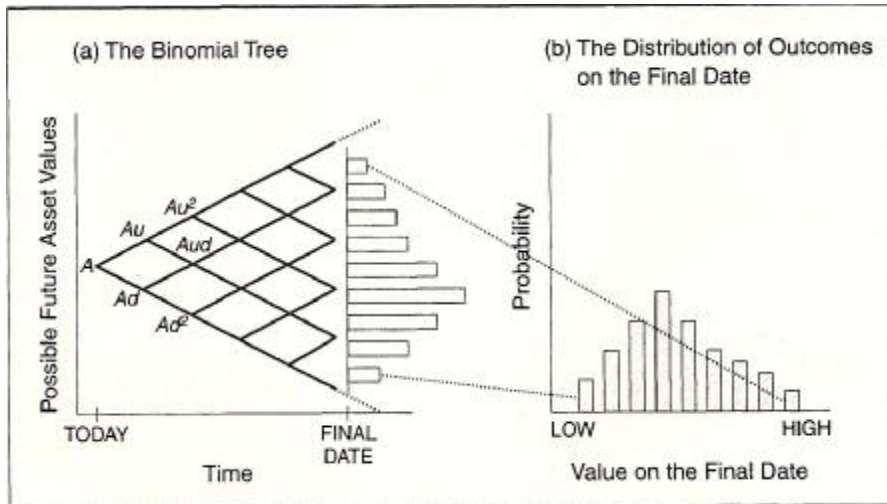
Figure 10, The binomial tree and the distribution of outcomes on the final date (source Kodukala and Papudesu, 2006).

3.5 Computing the value of a financial call option

The price of a call option is based on the no-arbitrage principle. Suppose a portfolio consisting of a long position in a certain amount of the asset and short call position in the underlying asset. The amount of the underlying asset purchased is such that the position will be hedged against any change in the price of the asset at the expiration date of the option. The hedge portfolio is riskless, because the loss on the underlying asset is exactly offset by the gain on the short position in the call option (Fabozzi and Mondigliani, 2002)

The investment made in the hedged portfolio is equal to the cost of buying H (the hedge ratio, the amount of the asset purchased per call sold) amount of the asset minus the price received from selling the call option. So this is equal to HS – C, where

H = the hedge ratio
S = Current asset price
C = Current price of a call option

The hedged portfolio, which is riskless, should generate the riskfree rate (r_f). The amount invested in the hedged portfolio is HS – C, so the amount that should be generated one period from now is
$(1+r_f) * (HS – C)$

The payoff of the hedged portfolio will be the same whether the asset price goes up or down. If the asset goes up, the value will be uHS–C. If the asset goes down, the value will be dHS – C. Equating this with $(1+r_f) (HS – C)$ we get $(1+r_f) (HS – C) = uHS – C_u$ [or $(1+r_f) (HS – C) = dHS – C$]

23

So the call option price $C = [(1+r_f-d) / (u-d)] * C_u / (1+ r_f) + [(u-1-r_f) / (u-d)] * C_d / (1+r_f)$

Where $(1+r_f-d) / (u-d)$ is the risk neutral probability $= p_{binomial}$ and $[(u-1-r_f) / (u-d)] = 1-p_{binomial}$

This $p_{binomial}$ is not the same p as the "p in our decision tree". The risk neutral probabilities are a mathematical intermediate that will enable to discount the cash flows in the binomial tree using a risk free interest rate. The "p in the decision tree" is a subjective probability, the chance/probability that a certain event/scenario will occur. The "p in the decision tree" is discussed in paragraph 4.1.

In the following example how to value a real option is given. This example is based on the example from the book Project Valuation using Real Options.

Example 4 Valuation of a real option

A company can wait for a maximum of 5 years before releasing a new product without experiencing any substantial loss of revenues. The Discounted Cash Flow method (DCF) estimates that the Present Value is 160 million, while the investment to develop and market is 200 million. So the NPV of the project is -40 million. The volatility of the future cash flows is 30% and the risk free rate is 5%. The value of the option to wait can be calculated as follows:

1) First the input parameters are calculated:

- u = exponential (volatility * square (delta t)) = exp (0,30*square (1)) = 1.350
- d = 1/u = 1/1,350 = 0,741
- $p = [1+r_f – d] / (u-d) = [1+0,05– 0,741] / (1,350-0,741) = 0,510$

2) Then build the binomial tree of the project:

		t=0	t=1	t=2	t=3	t=4	t=5
		S					
asset price tree:		160	216	292	394	531	717
			119	160	216	292	394
				88	119	160	216
					65	88	119
						48	65
							36

Figure 11, binomial tree asset prices

At t= 0, the underlying asset value is the estimated PV, 160 million = S_0. After one year (at t = 1) the asset value either goes up or down, so 160* 1,350 = 216 (S_0u) or 160*0,741 = 119 (S_0d). The year after, the value could be S_0u^2 (292) or S_0ud (160) or S_0d^2 (88).

At t =3, the possible values are S_0u^3 = 394 or S_0u^2d = 216 or S_0d^2u = 119 or S_0d^3 = 65.

At t =4, the possible values are S_0u^4 = 531 or S_0u^3d = 292 or $S_0d^2u^2$ = 160 or S_0d^3u = 88 or S_0d^4 =48.

At t =5, the possible values are S_0u^5= 717 or S_0u^4d = 394 or $S_0d^2u^3$ = 216 or $S_0d^3u^2$ = 119 or S_0d^4u =65 or S_0d^5 = 36.

3) Solve the tree with backward induction:

At every node there is the choice to either invest in product development or to wait until the next time period. When the asset value goes up for 5 straight years, the asset value would be 717. If you invest in the project the NPV will be 717- 200 = 517 million. Waiting till the next period is useless, because the option becomes worthless if it is not exercised. So the option value at this node is 517. When the asset value is 36 (the right bottom corner in figure 11), the NPV is negative (36-200=-164). So the option will not be exercised. All these terminal nodes could be calculated in this way.

One step away from the last time step, starting at the top node: the expected value for keeping the option open at that node is [p * 517 + (1-p) * 194] / (1,05) = 341 million. Keeping the option open shows a higher value than exercise the option (the payoff of exercise would be 531-200 =331 million), so the choice is continue to wait.

Complete the option valuation binomial tree all the way to t=0 (figure 12).

		t=0	t=1	t=2	t=3	t=4	t=5
option prices		43	75	128	213	341	517
			14	27	53	101	194
				22	4	8	16
					0	0	0
						0	0
							0

Figure 12, binomial tree option prices

So the option to wait is worth 43 million (t= 0)

3.6 Financial Options and Real Options

In fact, the spending in the R&D has similarities with acquiring a financial call option (Kodukala and

Papudesu, 2006). A financial call option is the right, but not the obligation, to buy an underlying stock at a predetermined price (the strike price) on or before a predetermined date (Amram and Kulatilaka, 1998). When the stock price at maturity is higher than the strike price the financial call option will be exercised. The payoff then is the difference between the stock price and the strike price. When the stock price is lower than the strike price, the financial call option will not be exercised. The payoff then is zero. To acquire this financial call option the investor has to pay a premium for it. If the underlying asset is a non-financial asset the options is called a real option.

The amount spent in the R&D phase (costs of the FTES and material costs for testing) is seen as the cost of acquiring the call option, the premium. The present value of the projects that emerge from this (the PV of the different scenarios) is equal to the possible outcomes of the stock price. The investment to be made in the scenario is the strike price. If the scenario is viable, the present value of the cash inflows exceeds the needed initial investment, the payoff is the difference between the two. If not, the scenario will not be accepted and the payoff will be zero (Luerhmann, 1998)

3.7 Types of flexibilities

Traditional NPV makes implicit assumptions about an "expected scenario" of cash flows and presumes management's passive commitment to a certain "operating strategy". It assumes that the project will be initiated immediately and operated continuously until the end of a pre-specified expected useful life. However, managers have the flexibility to alter the strategy when things develop differently than expected. The types of flexibility that can be distinguished are (Trigeorgis, 1995):

1) A deferral option, this is the possibility to wait until more information about the outcomes of the project is available.

2) The option to abandon which gives an insurance against failure. It gives the right to sell the project's assets when things do not go as well as expected. It gives the right to make the investment in stages, and at each stage based on the new information available; the management could decide to proceed or to stop the project.

3) The option to make follow on investments (the option to expand). This is the possibility to adjust the scale of production when things develop favourably.

4) The contraction option. This is the option to scale back a project by selling a fraction of it for a fixed price.

5) Switching option. This is the option to vary the firm's output or its production methods.

3.8 The Discount rate used in NPV$_x$

The cash flows in the different scenarios have to be discounted by an appropriate discount rate, also called the opportunity cost of capital. This discount rate is the same discount rate as being used in computing the value of the underlying asset at the start of the binomial tree. There are two reasons for discounting a cash flow (Brealy and Myers, 2002). The first one is because a dollar today is worth more than a dollar tomorrow. A dollar today can be put in deposit and earn interest. The second reason is that a safe dollar is worth more than a risky one.

3.8.1 Weighted Average Cost of Capital

A discount rate which is often used to discount projects is the WACC, the weighed average cost of capital (Brealy and Myers, 2002). It is the calculation of a firm's cost of capital in which each category of capital is proportionately weighted. The assets of a company are financed by debt and equity. The WACC is the average of the costs of these sources of financing. The WACC shows the amount the company has to pay for every dollar it finances. The WACC is calculated by multiplying the cost of each capital component by its proportional weight and then summing:
*WACC = Cost of equity * (equity/ (debt+equity)) + Cost of debt * (debt/ (debt+equity)) * (1-tax rate)*

The WACC is often used by the management to determine the economic feasibility of new opportunities. It can be used as the benchmark discount rate and new projects then are compared with this WACC (Brealy and Myers, 2002 & Kodukala and Papudesu, 2006). If the risk of the new project is relatively low and the project represents "business as usual", the WACC is a proper discount rate. For the projects with a higher risk, the WACC should be adjusted. So the WACC is the appropriate discount rate to use for projects with risk that are similar to that of the overall firm.

3.8.2 Two types of risk

There are two different types of risks that can be distinguished, namely market risk and private risk (Fabozzi and Mondigliani, 2002). Market risk is risk that cannot be diversified away. It is also called systematic risk. It is the risk inherent to the entire market. The value of an investment may decline because of economic changes that have impact on the whole market. Economic changes are for example a decline in the interest rates or inflation. These events have influence on the entire economy. Private risk or unique risk is the risk that is specific to a company. For example, the risk of failing to develop a new technology is a private risk for a high-tech company. The risk of not finding a

large amount of oil in a particular oil field is the private risk for an oil company.

Investors are willing to pay a risk premium for cash flows which are market driven, but not for private risk. This is because private risk could be diversified away by the investors. When there is no risk at all, the risk free rate should be used to discount the cash flows because of the time value of money. When the cash flows are market driven, a risk premium should be added to the risk free rate. The size of the risk premium depends on the risk level of the project. When investors are taking higher risks, they expect a higher return for taking the higher risks. So it is only reasonable to discount the market driven project cash flows at a rate that is defined by the risk level of the projects (Kodukala and Papudesu, 2006).

In a decision tree the cash flows must be discounted as you fold them back toward time zero. At different points in the tree, different discount rates should be used (Margolis, 2003). The discount rate depends on the type of risks in the decision tree. When the type of risk is unique/private risk, this risk can be diversified away by the investors. The risk free rate should then be used as the discount rate. When the cash flow stream in the tree is dictated by market risk, the non diversifiable risk, the WACC should be used to discount the cash flows.

3.9 Conclusion

Traditional valuation methods like the Net Present Value (NPV) overlooked the flexibility of the management to alter the course of a project in response to changing conditions. Projects are assumed to proceed as planned, regardless of future events. The NPV method precludes operational flexibilities such as the abandonment and the expansion of a project. These flexibilities of the management have a value which is not captured in the traditional methods. With Real Options it is possible to capture the value of these flexibilities. Real options see the investment in R&D projects as making a relatively (compared with the total investment in the project) small initial investment which creates opportunities to make a further investment in the next stage of the project. Till the moment the product is being brought into the market, the organisation can decide to eventually cut the funding in the project and not to market the project. This means, when the outcome of the R&D project is negative, the NPV of this scenario will not be counted in the valuation of the project. The only losses incurred then are the small initial investment.

It is important that the tool of Philips ADL includes the flexibility of the management to response to changing conditions of the whole project. During the predevelopment stage more information can be gathered about the progress of the project and based on this information, the management decides whether the project is still worth funding. When it is known that the NPV of a scenario is negative, the

management could decide not making the initial investment in that particular scenario. This means that the scenarios with a negative NPV should be left out in the calculation of the value of the project. This can be achieved by modeling the option to abandon the project in the tool.

Another important issue is the discount rate used for the discounting of the cash flows of the project. Projects have to be discounted at the right discount rate because any project investment requires capital which is financed by investors. When investors are taking higher risks, they expect a higher return for taking these higher risks. The discount rate depends on the type of risk that drives the cash flows. There are two phases to be distinguished in the organisation. The first phase is the predevelopment stage. The second phase takes place when the predevelopment is finished and the product is bringing to the market. In the predevelopment stage I suggest to use the risk free rate and in the second stage the WACC (which is currently used by Philips ADL) is an appropriate discount rate, because in this second phase the cash flows are market driven.

In this part the theory of Real Options and the Discount Rate has been discussed. In the next chapter the tool will be discussed in more detail using the theory.

Chapter 4 Application of the theory

In this chapter the research questions "Is the current model, which is based on Real Options theory, correct?" and "Which improvements are needed for the current tool?" will be answered. In this chapter, the parameters in the formula mentioned in the last chapter will be explained more explicitly one by one. In paragraph 4.1 the mathematics behind the calculation of the chances for the different scenarios are described. Paragraph 4.2 will explain how the Net Present Value of the different scenarios is calculated. In paragraph 4.3 the current Discount Rate used to discount the cash flows in the different scenarios is discussed. Paragraph 4.4 gives a summary of the current tool. Finally, this chapter ends with a conclusion in paragraph 4.5.

<u>4.1 The calculation of the chances of the different scenarios (p_x)</u>

When each key uncertainty of the project has influence on just one scenario, the success chance of a scenario is simply calculated by multiplying "the success chances of all the key uncertainties which are necessary for that particular scenario" and then multiplying this chance with the failure chances of the previous scenarios. However, in most situations, the key uncertainties have influence on multiple scenarios. This is the reason that the formula mentioned in paragraph 3.2 is not entirely correct. In this paragraph the adjustment of the formula will be discussed.

p_x is defined as the feasibility of scenario x and p_x' as the success chance of scenario x GIVEN scenarios 1, 2…x-1 failed.

The feasibility of scenario x is defined as the chance that the key uncertainties for scenario x are all successfully resolved. The success chance of scenario x is defined as the chance that scenario x is executed. At this moment the chance of success for scenario 2 is calculated by "the chance that scenario 1 is not feasible" * "the feasibility of scenario 2", $(1 - p_1) * p_2$. Adjusting this formula with conditional chances gives the following formulas:

p_1' = p_1

p_2' = p (S_2 feasible | S_1 not a success)
     = p (S_2 feasible & S_1 not a success) / p (S_1 not a success)
     = p (S_2 feasible & S_1 not a success / $(1-p_1$'))

p_3' = p (S_3 feasible | [S_1 not a success & S_2 not a success])
     = p (S_3 feasible & S_1 not a success & S_2 not a success) / p (S_1 not a success & S_2 not a success)

Because $p(S_1 \text{ not a success} \& S_2 \text{ not a success}) = p(S_1 \text{ not a success}) * p(S_2 \text{ not a success} \mid S_1 \text{ not a success}) = (1-p_1') * (1-p_2')$, this gives the following formula for p_3':

$$p_3' = p(S_3 \text{ feasible} \& S_1 \text{ not a success} \& S_2 \text{ not a success}) / [(1-p_1') * (1-p_2')]$$

$$p_N' = p(S_N \text{ feasible} \mid [S_1 \text{ not a success} \& S_2 \text{ not a success} \& \dots \& S_{N-1} \text{ not a success}])$$
$$= p(S_N \text{ feasible} \& S_1 \text{ not a success} \& S_2 \text{ not a success} \& \dots \& S_{N-1} \text{ not a success}) / p(S_1 \text{ not a}$$
$$\text{success} \& S_2 \text{ not a success} \& \dots \& S_{N-1} \text{ not a success})$$

The old formula is: Value project = $p_1 * NPV_1 + p_2 * (1-p_1) * NPV_2 + p_3 * (1-p_2) * (1-p_1) * NPV_3 + \dots + p_x * (1-p_{x-1}) * (1-p_{x-2}) * \dots * (1-p_1) * NPV_x$

This formula is only allowed when all the key uncertainties for each scenario are different from the key uncertainties of the other scenarios. However, in almost all the projects, there is always at least one uncertainty which has influence on multiple scenarios. The conditional chances of the different scenarios are now calculated by making use of VBA Excel. See appendix B for the code. After the adjustment has been made, this gives the following decision tree (figure 13).
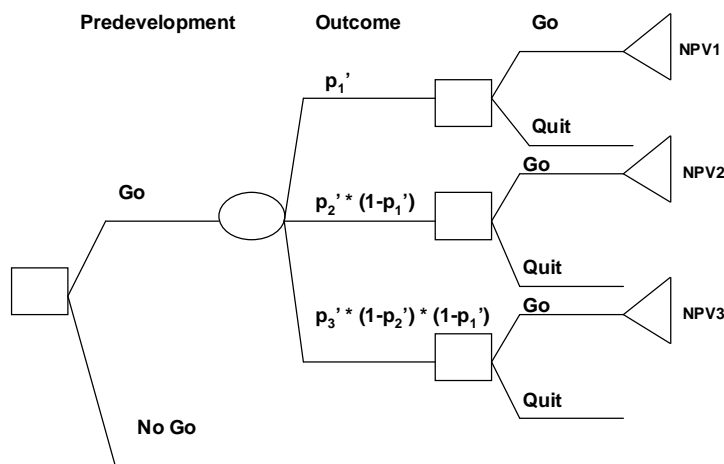

Figure 13, Adjusted Decision tree Philips ADL

New formula project is:

Value project = p_1' * NPV_1 + p_2' * (1- p_1') * NPV_2 + p_3' * (1-p_2') * (1- p_1') * NPV_3 + …+ p_x' * (1-p_{x-1}') * (1-p_{x-2}') *…* (1-p_1') * NPV_x

p_x' = The success chance of scenario x GIVEN scenarios 1…x-1 failed.

NPV_x = Net present value of scenario x

This formula is still not totally correct, because the cash flows of the different scenarios are not discounted in the predevelopment stage. In paragraph 4.5 a suggestion is given of how to adjust the formula.

In example 5 the calculations of the chances for the different scenarios are explained more explicitly.

Example 5

	Scenario 1	Scenario 2	Scenario 3
NPV	48	40	12

Key deliverable	Estimated Probability of Success (Current Date)				
A	70%		1	1	
B	60%		1		1
C	80%		1		1
D	70%			1	

Figure 14, summary example of a fictive project

A project has 4 key uncertainties, uncertainty A, B, C and D. The NPV of scenario 1 is 48 million, the NPV of scenario 2 is 40 million and scenario 3 has a NPV of 12 million. Scenario 1 requires uncertainty A, B and C, scenario 2 requires A and D and scenario 3 B and C. See figure 14. The "1" means that the key deliverable is required for the scenario.

If the success chance of a scenario is calculated by multiplying the chance of success from one scenario with the failure chance of scenario, the chances calculated will be too optimistic.

- Success chance of scenario 1 = success chance of key uncertainty A* success chance of key uncertainty B* success chance of key uncertainty C. This gives 0,7* 0,6* 0,8 = 33,6%

- Success chance of scenario 2 is: (1 - success chance of scenario 1) * success chance of key uncertainty A *success chance of key uncertainty D = (1- 0,336)* 0,7* 0,7 = 32,5%

- Success chance of scenario 3: (1 - success chance of scenario 1)*(1 - success chance of scenario 2)* success chance of key uncertainty B* success chance of key uncertainty C = 16,3%

If scenario 1 fails due to key uncertainty A, you know for sure that scenario 2 will also fail. This is because key uncertainty A has influence on both scenario 1 and scenario 2. So conditional chances have to be calculated. These are calculated by making use of vectors. There are 4 uncertainties, so there are 2^4 = 16 combinations (vectors). See figure 15.

Uncertainty 1   0   1   0   0   0   1   1   1   0   0   0   1   0   1   1   1

Uncertainty 2   0   0   1   0   0   1   0   0   1   1   0   1   1   0   1   1

Uncertainty 3   0   0   0   1   0   0   1   0   1   0   1   1   1   1   0   1

Uncertainty 4   0   0   0   0   1   0   0   1   0   1   1   0   1   1   1   1

Figure 15, The 16 possible vectors. The 1 means success of the uncertainty and the zero means failure of the uncertainty.

The vectors [1,1,1,0] and [1,1,1,1] mean that scenario 1 will succeed. This is a chance of (0,7*0,6*0,8*0,3) + (0,7*0,6*0,8*0,7) = 10,08+23,52 = 33,6%.

Scenario 1 will only fail when at least uncertainty A, B or C fail. But when uncertainty A fails, it is also for sure that scenario 2 will fail. So the success chance of scenario 2 are the vectors [1,0,0,1] and [1,0,1,1] and [1,1,0,1]. This is a chance of 25,48%.

The success chance of scenario 3 are the vector [0,1,1,1] and [0,1,1,0] . This is a chance of 14,4%.

The value of the project is the success chance of the scenario multiplied with the NPV of the scenario. This gives a value of 33.6%*48+25.48%*40+14.4%*12 = 28.05 million.

As you can see, the chances calculated with the vectors are much lower than the chances calculated before.

The value calculated is always the optimal value. There are no other combinations of the scenarios that will give a higher option value. The optimal combination always gives the priority to the scenario with the highest NPV and so on. The explanation for this is that a change in the sequence of the scenarios (for example do scenario 3 first and then 2 and then 1) will not change the success vectors. These vectors will still be the same. As a result this will not lead to a higher option value.

4.2 Calculation of the NPV of a scenario (NPV$_x$)

The NPV of each scenario is calculated by making use of the standard discounted cash flow method. There is the assumption that each particular scenario has just one NPV. However, in reality there is a range of possible outcomes of the NPV in each scenario. Suppose for example that the initial investment is a certain amount and that the PV is normal distributed like in figure 16.
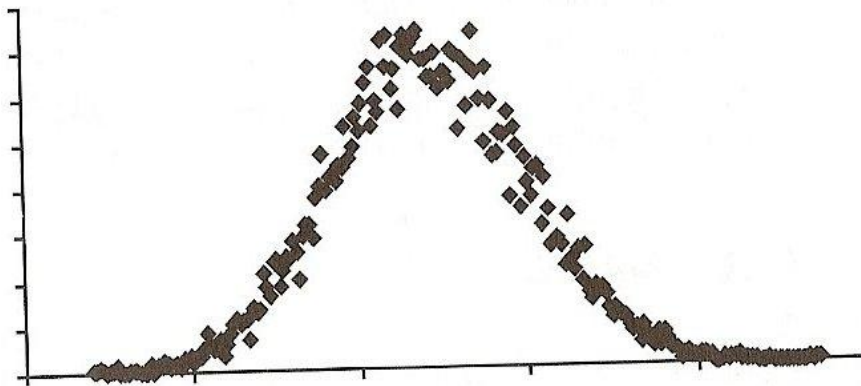
Figure 16, expected payoff distribution, with on the Y-as the probability and on the X-as the value of the PV.

The PV is not a certain amount, because a lot of different factors have influence on the PV. For example, the unit variable costs will decrease when the oil price decreases. Another factor which influences the PV is, for example, that the economy is growing stronger than expected. Because of the chance (even if it's a very small probability) that the PV could be higher than the initial investment, this has a real option value. This means that even in a scenario where the NPV is negative, the real option value of that particular scenario could be positive. So in NPV$_x$, the flexibilities (defer, abandon, contract, expand and switching, which were discussed in 3.7) to alter the operating strategy to adjust to changing market conditions have a value that is not captured in the current tool. This is because changes in the NPV of a scenario, and thus the value of the project, are only adjusted afterwards. To calculate the real options value of this flexibility, the binomial tree (see paragraph 3.4) could be used. However, these flexibilities of the management are hard to foresee, because the predevelopment takes a couple of years and bringing the product into the market takes some more years as well. So it is very difficult to estimate the input parameter "volatility of the cash flows", which means the value the flexibilities, could not be calculated. This is the reason why just the

NPV method is used to calculate the NPV of a particular scenario.

4.3 Current risk adjusted discount rate

There are two phases to be distinguished. The first phase is the predevelopment stage. The second phase takes place when the predevelopment has been finished and the product is being brought into the market. The cash flows of the different scenarios are discounted to this moment, the moment the product is being brought into the market. In this phase the WACC is used as the discount factor for all the different projects. This WACC is dictated by Philips. In this phase the cash flows are market driven (for example the market demand). However, some projects are much more risky than the average projects. So for the more risky projects a discount rate higher than the WACC should be used. For the safer projects, the WACC is a proper discount rate.

In the predevelopment the project success is determined by the effectiveness of the new technology and the efficiency of the organisation in completing the project. As a result, the predevelopment phase is considered to be controlled by private risk and not to market risk. The cash flows of the project are not subject to the market forces in this phase. When this is the case, the risk free rate should be used (discounting because of the time value of money) to discount cash flows in this stage. In the current model the cash flows of the different scenarios are not discounted in this first stage of the project. This is caused by the fact that the duration of this first stage for the different projects is not known. However, the cash flows should be discounted at a risk free rate because otherwise the NPV calculated will be too optimistic.

4.4 Value of the total project

The flexibility to respond to changes in the technology outlook are captured in the current tool, see the decision tree in figure 8. It captures the value of the option to abandon the project. The tool quantifies the technological risks and creates value by structuring the predevelopment stage into go/no-go decisions points that exploit the option to abandon the project (Boer, 2003). This value is directly captured in the valuation of the project because the negative scenarios are left out in the expected value of the project. This approach of computing the expected value of the project is a form of real options thinking.

An option is the opportunity to make a decision after you see how events unfold. On the decision date, if events turned out well, you will make one decision, but if they turned out poorly you will make another. Valuating this option (the option to abandon if the situation develops unfavourably) is not

equal to the value that is given to a project in the current situation. In the current situation the way "real options thinking" would value the project as a whole is calculated. This is different from the value of the option to abandon the project. To calculate this option value, the value of the opportunity without this option should be calculated first. The difference between these amounts then is the value of the option to abandon.

Example 6

A project has 5 different scenarios, see figure 17. A standard NPV analysis which taken into account all the possible scenarios will value this as 48 * 0,336+ 40 * 0.2548 *1 2 * 10.08 +-50 * 0.984 + -10 * 0.11 = 16.51 million.

Scenario	NPV	Success chance (%)
Scenario 1	48	33,6
Scenario 2	40	25,48
Scenario 3	12	10,08
Scenario 4	-50	19,84
Scenario 5	-10	11

Figure 17, summary example 6.

In real options thinking the flexibility to change the course of action is taken into account. So the negative outcomes will be avoided, because if the outcome is bad, the management will stop making further investment in the project (abandon). Real options would value this project as 48 * 0,336 + 40 * 0.2548* 12 * 10.08 = 27.53 million. So the option to abandon is worth 27.53 – 16.51 = 11.02 million.

4.5 Conclusion

The current tool is correct, however there are some improvements which can be made. First of all the chances assigned to the different scenarios are not entirely correct, because in most situations the key uncertainties of the project have influence on multiple scenarios. This means that conditional chances have to be calculated instead of it. During this thesis, this problem has been solved. The chances are now computed by making use of VBA Excel (see also Appendix B). This code is written by Ruud Gal (the innovation manager).

The second improvement that can be made is the discounting of the cash flows in the first stage of the projects, the predevelopment stage. In the current model the cash flows of the scenarios are not

discounted in this stage, because the duration of this stage is not known for certain. However, as mentioned before, the cash flows should be discounted using the risk free rate, because of the time value of money. This has not yet been implemented. A possible way to adjust the formula is as follows:

Adjusted Value project = $[p_1' * NPV_1 + p_2' * (1- p_1') * NPV_2 + p_3' * (1-p_2') * (1- p_1') * NPV_3 + …+ p_x' * (1-p_{x-1}') * (1-p_{x-2}') *…* (1-p_1') * NPV_x] / (1+\text{riskfree rate})^d$

where d = expected staying time of the project in the predevelopment stage.

In the current situation, the NPV of each scenario is the NPV at the moment the product is bringing to the market. By discounting the expected value of the total project at a risk free rate during the predevelopment stage, the NPV of the project at the start of the predevelopment is computed.

Chapter 5 Subjective probability assessment

5.1 Introduction

In this chapter the two questions "Which methods could be used to improve the input parameter estimated chance of technical success?" and "Is the method applicable for Philips ADL?" will be answered. This chapter consists of two parts. The first part is the theoretical part. In this part the methods which can be used to estimate the technical success chance will be discussed. In the second part the results of the pilot study is shown.

Part I: Theoretical part

5.2 Introduction subjective probability

The elicitation and use of expert opinions is increasingly important. Often new projects are so unique, which makes it almost impossible to use historical data of projects to judge about the success chance of the new projects. The technologists are turning in greater numbers to "expert systems" (Cooke, 1991). These experts have a lot of accumulated knowledge, which can be very useful in judging the new projects.

5.3 Definition subjective probability

The definition of Laplace of probability is the ratio of the number of cases favorable to the event to the number of all possible cases; each case is assumed to be equally likely. This is also called the objective probability. When throwing a dice, the chance on a six is 1/6. There is no discussion about it. On the other hand there is the subjective probability. This probability expresses the feeling of an individual. The definition of subjective probability is (Hampton, Moore and Thomas, 1973):

Subjective probability is considered a quantification of uncertainty. It represents the extent to which a coherent person believes a statement is true, based on the information available to him at that time.

A subjective probability describes an individual's personal judgement about how likely a particular event is to occur. It is not based on any precise computation but is often a reasonable assessment by a knowledgeable person. The probability is normally expressed on a scale between the 0 and 1. An infrequent event will have a subjective probability close to zero and an event that is very common will have a subjective probability close to one. This type of estimating is called point estimation. It is also

possible that the estimator has to assess the whole distribution of a particular event (by using methods like psychometric ranking and probability density functions). But the rest of this chapter will be focused on point estimation, because in the current situation of ADL the project leader estimates the chance of success of a key uncertainty as just one number.

5.4 Methods for eliciting subjective chances

There are different methods that can be used to estimate subjective chances. It is possible to estimate the chances individually or in a group (Hampton, Moore and Thomas, 1973).

5.4.1 Individual methods

When using the individual method, there is a distinction between the direct and indirect method. In the direct method the person is directly interrogated concerning his judgments. The decision maker is asked to express his beliefs by a number between 0 and 1. In the indirect method the person's assessment is concluded from his preferences between possible decisions. This technique is divided into two methods, the lottery technique (bet method) and the equivalent urn method.

The Bet method
In this technique the decision maker answers a series of yes-no questions in terms of simple betting odds. His subjective probability for the occurrence of the event is then implied from the odds required to make him indifferent between two offered bets. For example: If sales next month exceed 1000 units, he gets 50 dollar, otherwise nothing. So there exists an amount in dollar (Y), which makes the two bets equally attractive to him.

EV (expected value) $= p50 + (1-p) 0$, where
p= probability that sales next month exceed 1000 and Y= amount of dollar receiving. EV=Y, p= Y/50.

Equivalent urn method
In the equivalent urn, the urn consists of the chances of occurrence of the events. The urn contains several colored balls, within each ball means the occurrence of an event. The judger assesses what mix of balls will make the urn equivalent to his feelings.

The advantage of these indirect methods is that the measurement error, the discrepancy between reported and actually held judgment, will be obviated by these techniques (Savage, 1954).

5.4.2 Group methods

When using the group method approach, there are three different methods distinguished (Van de Ven and Delbecq, 1974).

Interacting groups

At the beginning of the discussion, the statement of the problem is made. This is followed by an unstructured group discussion for generating information and pooling judgments among participants. The meeting ends with a majority voting procedure. This method is an unstructured face-to-face group meeting. The administrative costs and time for the preparation are low and the time to obtain the results is immediately after the meeting finishes (which takes approximately 1,5 hours).

Nominal Group Technique (NGT)

This method is a structured face-to-face group meeting. This is a meeting with a structured format. At the beginning of the discussion, the statement of the problem is made. Then the members of the group generate their ideas of a problem individually on a paper (in case the problem is to estimate chances, the members starts with making the estimates individually on a paper). After this phase, the members present their ideas (estimates) to the group. When they have presented their ideas (estimates), there is a discussion of the ideas (estimates). The session ends with a voting procedure. The administrative costs and time for the preparation are medium and the time to obtain the results is right after the meeting finishes (which takes approximately 1,5 hours).

Delphi method

The core of this method is a repeated consolation of experts (Dalkey, 1968). Each participant starts with filling out a questionnaire and gets feedback concerning the answers (estimates) of all the participants. With this new information the participant fills out the questionnaire again, but now with explanation on the questions which were completely different from the other participants. This information serves as useful information for the other participants. The participant can change his beliefs after the evaluation of the new information from the others. This process is continuously repeated as long as necessary. Unlike the Interacting Group and the NGT, the participants in the Delphi method do not meet face-to-face for group decision-making. The administrative costs and time for the preparation are high and the time to obtain the results is a few months.

In the three group methods discussed before, it is possible to assign higher weights to a judger if the judger is a specialist on one of the technological area (Winkler 1968). This can be done by the participants of the group individually, or by someone outside the group.

5.5 Effectiveness of the methods in terms of accuracy

Gustafson et al (1973) tested the effectiveness of independent individuals, interacting, NGT and the Delphi method on a problem of subjective probability estimation. The criteria he used were the absolute mean percentage error between methods and the variance of estimates across groups. The mean percentage error indicates the degree of bias and the variance measure indicates the degree of consistency (the smaller the differences in the estimates between the members of the group, the more consistent the estimates are). The results showed that the NGT was the best in terms of the lowest percentage of errors and variability of estimates. Second best was the interacting group and third was the independent individual. The Delphi method was the worst. This was caused by the fact that a derivative process called Estimate-Feedback-Estimate was used instead of the real Delhi method, because the Delphi method was too expensive. In the experiments carried out by Dalkey (1968) the respondents estimated the accuracy of a set of facts. The results showed that the estimates with more persons are more accurate than the estimation carried out by one person.

5.6 Effectiveness of the methods in terms of ideas / information generated

The ideas / information generated in a process are a very important gauge. The greater the quantity of ideas / information generated, the greater the number of ideas / information are considered in making a decision. This implicates a better decision (Van de Ven and Delbecq, 1971). Osborn (1957) showed that an average person could think up twice as many ideas when working in a group instead of working alone. These are also the results of Taylor, Berry and Block (1958). Their statement was that group participation does facilitate the production of ideas. Taylor, Berry and Block (1958) also compared the nominal group method with the interaction group. They compared these two methods in terms of three measures, namely the mean number of unique ideas, the mean total number of ideas and the quality of ideas. Based on these three measures, the nominal group was significantly superior to the interaction group in generating information relevant to the problem. A study from Van de Ven and Delbecq (1974) also showed that the NGT and the Delphi method were the methods that generated the most ideas. Their study also measured the perceived group satisfaction. This is the satisfaction the participants perceive with the group process and the decision outcomes. This is important because a higher satisfaction will lead to a higher probability of solution adoption.

5.7 Phases in estimating subjective probabilities

The process of estimating probabilities of technical success for R&D projects can be being composed in four phases, the perception phase, the evaluation phase, the transformation phase and the review

phase (Rubenstein and Schroder, 1977):

1. In the perception phase the perceiving of the project attributes takes place.

2. In the evaluation phase qualitative judgment about the technical chance of success will be made.

3. In the transformation phase the qualitative judgment will be transformed into numerical values. These values mean the degree of belief, also called the subjective probabilities.

4. In the review phase, the actual subjective probabilities are scrutinized with respect to their communicability. The communicated subjective probability may differ from the actual subjective probability if they think this is necessary.

5.8 Variables, which influenced the subjective probability

There are three different sorts of variables, which have influence on the communicated subjective probability of technical success of the project (Rubenstein and Schroder, 1977). These are the personal variables, organization variables and situational variables. Personal variables have a direct influence on the communicated subjective probability, while organizational and situational variables act indirectly via the personal variables.

- Personal variables: These are the characteristics of the assessors which have influence on the assessor's ability to perceive and evaluate a project's attributes and to transform their belief into a numerical value, as well as their willingness to transmit their actual subjective probabilities of technical success. Most important among them are education and previous experience. Psychological aspects of the probability assessment are also an important aspect. The finding of Kahneman and Tversky (1972) showed that people tend to solve complex tasks of assessing probabilities by simplifying the assessment problem with the application of a few heuristic principles. For example the heuristic representatives, the probability is determined by the degree to which is similar in essential characteristics to its parent population. This can lead to a cognitive bias.

- Organizational variables are the variables such as the assessor position in the company hierarchy.

- Situational variables express the influences of factors, which are specific to the project to be assessed. For example the assessor specific relation toward the project like the project responsibility or his position with respect to the project generation.

Assessors who generated the project idea or did participate in the idea generation will assign a higher chance of technical success than a nonoriginator. This is because they have the tendency to upgrade positive and downgrade negative circumstances. When it is necessary they will communicate a higher probability of success than the actual subjective probability to get acceptance for the project. A test conducted by Rubenstein and Schroder (1972) showed that in 53 out of the 90 comparisons between an originator and a nonoriginator the estimate given by the originator was higher. In 20 comparisons there were no differences and in just 17 cases the nonoriginator was more optimistic.

Assessors with project responsibility (responsibility to project implementation with the planning and control functions included) will assign higher probabilities of success. This is because of their enthusiasm. Enthusiasm is associated with downgrading negative and upgrading positive aspects. This optimism is of more weight than the insurance against potential failure of the project by assessing lower probability of success (results shown by Rubenstein and Schroder).

In the next part the application of the theory takes place.

Part II: Application of the subjective probability theory

Using the theory from Rubenstein and Schroder (1972) I will discuss the assessment of the chance of success of the different key uncertainties by the project leaders in more detail.

The project leader is the one who determines the most important key uncertainties of the project. After this process, he will assign the chance of technical success to each key uncertainty. At this moment the project leaders are using the direct individual method. The assessor is directly interrogated concerning his judgments. The decision maker is asked to estimate the current chance of technical success by a number between 0 and 1. They also have to give a prediction of the chance of success three months from now, assuming that everything is going perfect.

The project leaders are well educated and very experienced. They do have the expert knowledge, so they have the ability to estimate the chance of success of the different key uncertainties. However, some projects have a very broad scope. It is possible that due to their lack of knowledge, they are not

capable of judging the key uncertainties properly. So in this case it is the lack of ability to give a proper estimation.

As Rubenstein and Schroder point out, the communicated subjective probability is not always equal to their actual degree of belief. Because of information asymmetry (the project leader has more information about the project than the innovation manager has), it is possible for the project leader to manipulate the estimated chances. When it is necessary to get acceptance for the project, the project leader will assign relatively high probabilities to the key uncertainties because these higher chances will lead to a higher financial option value of the project. A higher value indicates a better project, so the project is getting more FTES allocated. When the project got the FTES allocated, the project leader will be more cautious in the estimates to insure him against potential failure. In the current situation the project leader is the only person who estimates the chances. So there is no control over these assessed probabilities.

The project leader is always involved in the originating of the project and he has a high project responsibility. As a result of this, the project leader will have the tendency to upgrade positive and downgrade negative circumstances. I think this should not always be seen as a disadvantage. Sometimes it is necessary to be positive, because this will stimulate the motivation of the whole project team.

In the past (before the current model was introduced) the project leaders did not have to estimate the chance of technical success explicitly. As a result, they are not really familiar with the process of estimating chances. The more they estimate, the more feeling they will develop for this process. This will result in better estimates.

In the current situation the project leader is the only person who estimates the chances of success. In this situation it can easily lead to the manipulation of the chances. This is the reason why I suggested to introduce a small committee. A committee helps the project leader to estimate chances and the defining of the key uncertainties of the project. In the next paragraph I will show the results of the pilot study.

5.9 Pilot study

I introduced a small committee because the estimation of chances with just one person can lead to manipulation or incorrect estimates. This is also what the literature suggests, using the group approach in favour of the individual judgment. Studies from Gustafson et al (1973) and Dalkey (1969) showed that estimates made by individuals are less accurate than the group method. And besides,

by using the group approach more information relevant for the problem will be generated (Delbecq and Van de Ven, 1971). The greater the quantity of information generated, the greater the number of information are considered in making a decision. The other members of the committee can help the project leader to define the most important key uncertainties.

The group method I chose was the nominal group technique. The reason for this method is that the Delphi method takes too long to get results and the costs involved are very high. The other technique left was the interaction group. The study from Gustafson (1973) showed that the nominal group technique has the lowest percentage of measurement errors. Delbecq and Van de Ven (1974) showed that the nominal group technique has the highest perceived satisfaction by the participants. To improve the validity of the estimates, a small committee was established. Besides the project leader, two extra estimators were added to the estimation process. These two estimators have a lot of technological expertise and experience, and also very important: they are independent.

At the beginning of the group meeting the project leader started with his introduction of the project. He defined his key uncertainties of the project. After this, the rest of the group gave their view on the project. After the evaluation of these uncertainties, they started with the assessment of the chances of each key deliverable individually. One of the members of the group did not really want to estimate certain uncertainties because he does not possess the expert knowledge for it. For the key deliverables, where the estimates significantly differed from each other (10% or more), a general discussion was required to explain the differences. There were hardly any significant differences because the other independent estimator was not really independent. He was already involved in the project. After the discussion, with the new information generated in the discussion, each individual estimated the success chances again. The end result was the pooled outcome of the individual estimates. The assessor who did not really want to estimate, mentioned that he only wanted to estimate, if there would be lower weights assigned to his opinions. After the meeting, I asked about the satisfaction perceived with this group process. They thought it was useful.

5.10 Conclusion

There are different methods that could be used to improve the estimation of the project leaders. It is possible to estimate individually and in a group. Literature study showed that the group approach is more accurate than the individual method. The three methods for the group approach are the Interaction group, the Delphi method and the Nominal group technique. Literature study showed that the Nominal group technique (NGT), a structured face-to-face group meeting, is the best method of these three methods.

The pilot study showed that the meeting helped to evaluate the key deliverables. Some uncertainties were not really uncertainties and some uncertainties were "forgotten". Using the method to estimate the chances is a more difficult matter, because the independent estimators only want to assess the uncertainties when they have the expert knowledge. To implement the Nominal Group technique I will advise the following method:

Search for two independent estimators who are independent of the project and have a lot of knowledge. Before the meeting the two independent estimators have to be informed by the project leader about the project (by sending some important documents), so they can be well prepared for the meeting. The actual meeting then starts with a short introduction of the project by the project leader. After this introduction, the members discuss about the key uncertainties of the project. When they have reached consensus about the key uncertainties, they individually estimate the success chance of each key uncertainty. The success chance of each key uncertainty then is the mean of the estimates of the members of the group.

Chapter 6 Conclusions and Recommendations

Conclusions

In chapter 3 the research question "Which are the most important characteristics of Real Options for the valuation of R&D products?" is discussed. Chapter 4 answered the research questions "Is the current model, which is based on Real Options theory, correct?" and "Which improvements are needed for the current tool?". In chapter 5 the research questions "Which methods could be used to improve the input parameter estimated chance of technical success?" and "Is the method applicable for ADL?" are discussed.

Question1: Which are the most important characteristics of Real Options for the valuation of R&D products?

Answer: The most important characteristics of Real Options are the uncertainty of the underlying asset (for example the outcome of the R&D project) and the flexibility of the management to deal with this uncertainty. Real Options capture the value of the flexibility of the management to alter the course of a project in response to changing conditions. After a small initial investment (compared with the total investment in the project), the management can gather more information about the progress of the project and market characteristics and based on this information change the course of action.

Question 2 and 3: Is the current model, which is based on Real Options theory, correct? and Which improvements are needed for the current tool?

Answer: The current tool is correct; however some improvements could be made. The first adjustment which could be made is the assigning of the chances to the different scenarios. Before I started with this thesis the chances assigned to the different scenarios were not entirely calculated correctly, because in most of the projects the scenarios have key uncertainties which influenced multiple scenarios. This means that conditional chances have to be calculated. These conditional chances are now calculated by making use of VBA Excel. The second improvement that can be made is the discounting of the cash flows in the first stage of the projects. In the current model the cash flows of the scenarios are not discounted in the first stage, because the duration of this first stage is not known. However, the cash flows should be discounted using the risk free rate because of the time value of money.

Question 4: Which methods could be used to improve the input parameter "estimated chance of technical success"?

Answer: Literature study showed it is possible to estimate individually or in a group. The literature

study showed that the group approach is more accurate than the individual method. The three methods for the group approach are the Interaction group, the Delphi method and the Nominal group technique. The Nominal group technique (NGT), a structured face-to-face group meeting, is the best method of these three methods.

Question 5: Is the method applicable for ADL?

Answer: A pilot study was conducted to see if the NGT method is applicable for Philips ADL. The pilot study showed that the meeting was really useful in the evaluation of the key deliverables. Some uncertainties were not really uncertainties and some uncertainties were "forgotten". Using the method to estimate the chances is a more difficult matter, because the independent estimators only want to assess the uncertainties when they have the expert knowledge.

Recommendations

After all the research I have come up with three recommendations:

1. Before I started with this thesis the chances assigned to the different scenarios were not calculated entirely correct, because in most of the projects the scenarios have key uncertainties which influenced multiple scenarios. This means that conditional chances have to be computed.

2. The second recommendation is the introducing of a discount rate in the predevelopment stage. In the current model, the cash flows of the scenarios are not discounted in this stage, because the duration of this first stage is not known for certain. However, I recommend using a risk free rate to discount the cash flows in this phase, because of the time value of money. A possible way of adjusting the formula is as follows:

Adjusted Value project = $[p_1' * NPV_1 + p_2' * (1 - p_1') * NPV_2 + p_3' * (1 - p_2') * (1 - p_1') * NPV_3 + \ldots + p_x' * (1 - p_{x-1}') * (1 - p_{x-2}') * \ldots * (1 - p_1') * NPV_x] / (1 + \text{riskfree rate})^d$

where d = expected staying time of the project in the predevelopment stage.

3. In the current model the project leader is the only person who estimates the success chances of the key deliverables. Because of information asymmetry it is possible for the project leaders to manipulate these chances. This is the reason why I suggest introducing a group process for the big (in terms of NPV) projects. By estimating the chances in a group, these manipulations will be reduced. And besides this advantage, the measurement errors will also

be reduced. Finally, the members of the group could help the project leader to define the most important uncertainties of the project. The pilot study showed that this method is very useful.

Interesting issues

There are also some other interesting issues I want to mention. The first one is the introducing of FTES needed for each key uncertainty. At this moment the FTES needed for the whole project is given, but I think it is better to split these FTES into the FTES per key uncertainty. In the case where it is not possible to solve all key uncertainties, this information is necessary to determine a scheme (to determine the sequence in which the different uncertainty should be solved), which optimizes the option value of the project. The current tool is used as a management portfolio tool. By making these changes, the tool can also be used as a project tool. The second subject is using a distribution of the chances instead of the current point estimation. With a distrubution of the chances a sensitivity analysis can be conducted (using Crystal Ball for example). The option value is calculated by the chances given by the assessor, but these chances can vary. What is the impact on the option value when the chance of one uncertainty is not 60% but 50%? What is the impact on the option value when two uncertainties vary together? With sensitivity analysis the minimal, most likely and maximum option value of the project, could be computed. With this information it is possible to compare projects with each other more explicitly.

Further research

There are two subjects I would like to mention for further research:

1 Collect the data of the project leader's estimates per key uncertainty. As mentioned before, I recommend estimating the success chances of the different key uncertainties in a group. This process of estimating will increase the accuracy of the estimates. However, this process takes a lot of time from the independent estimators. This means it cannot be used for each individual project. It may be possible, by collecting the data of the e project leader's estimates for a long period of time, and analyzing this collected data with the use of statistics, to tell more about the reliability of the estimates of the project leaders.

2 Check for the possibility to introduce real options value in NPV_x. It is very difficult to estimate the volatility factor of a new project. An approach could be to use the data from historical projects, which is assumed to have cash flows similar to the project being considered. However, each project is very unique, so I am not sure if this information acquired is valid.

Appendix A

Project Name	**Name**	Expected Next Milestone	Average Planned CDL FTE			Output Scenario 1	Output Scenario 2	Output Scenario 3	Output Scenario 4
Project Number	Number	MS Number		Name Scenario		One	Two	Three	
		nov-06		Estimated NPV		100,00	50,00	25,00	
				Important: in order of NPV					

Responsible	Key Deliverable - technical, commercial, business	Estimated Probability of Success (Current Date)	Estimated Probability of Success (3 months from now)	Impact on Specs & Timing, Ramp-Up Speed in case of Failure				
					Give 1 if positive outcome is required			
CDL	Key uncertainty 1	60%	80%		1		1	
CDL	Key uncertainty 2	60%	70%		1	1	1	
CDL	Key uncertainty 3	80%	90%			1		
CDL	Key uncertainty 4	40%	50%		1			
GTD/SG HID	Key uncertainty 5	90%	90%		1	1	1	
GPT HID	Key uncertainty 6	53%	53%		1	1	1	
Supplier	Key uncertainty 7	50%	80%			1		

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Probability per Scenario	6,9%	8,7%	6,2%	0,0%
Contribution to Option Value	6,9	4,4	1,5	0,0

Current Option Value	**12,8**	**Meuro**
Target Option Value after Period	21,5	Meuro

Datum
december 11, 2006

Appendix B

The code is based on example 5, searching for non overlapping vectors and attribute these vectors to the different scenarios.

This is a user-defined function, which calculates the probability a scenario will be selected / occur.

```
Function OptionProbability(ByVal RiskVector As Range, _
      ByVal RisksPerOutputScenarioMatrix As Range) As Single
```

ColumnIndex	Nr of scenarios (the one for which probability of success is calculated)
RiskVectorLength	Number of key deliverables that have a probability of success
PossibleOutputScenaioVectors	A set of output scenarios (combinations of 1 and 0s) that are possible and relevant for the output scenario for which probability of success is to be calculated
ProbabilityNonOverlapWithEarlierScenario	If a possible output scenario is overlapping (already addressed) by an earlier/more preferred output scenario it's impact on the probability of success to be calculated will be ignored

```
Dim i, j, ColumnIndex, ArrowRoy, ArrowCol As Long, _
   RiskVectorLength As Integer, _
   PossibleOutputScenarioVectors() As Single, _
   ProbabilityNonOverlapWithEarlierScenario() As Single

 On Error GoTo ErrorExit
 Application.ScreenUpdating = False
```

Initialize riskvectorlength

```
RiskVectorLength = RiskVector.Rows.Count


While RiskVectorLength > 1 And _
     (RiskVector.Cells(RiskVectorLength,1).Value=0 Or IsEmpty(RiskVector.Cells(RiskVectorLength,
      1).Value))
     RiskVectorLength = RiskVectorLength – 1
```

```vba
Application.Volatile
If RiskVector Is Nothing Then
MsgBox "Macro Ended, RiskVector Empty"
Application.StatusBar = ""                    'Handle empty riskvectors, error handling
Application.ScreenUpdating = True
End
    End If


If RisksPerOutputScenarioMatrix Is Nothing Then
    MsgBox "Macro Ended, Risks per Output Scenario Matrix Empty"
    Application.StatusBar = ""          'Handle emptyriskperoutputscenariomatrix, error handling
    End
    Application.ScreenUpdating = True
End If

'Calculate the number of outputscenarios that have to be taken into account and re-dimension
'possibleoutputscenariovectors array

ColumnIndex = RisksPerOutputScenarioMatrix.Columns.Count
ReDim PossibleOutputScenarioVectors(RiskVectorLength)



'For each key deliverable that may impact the probability of success, check whether the output
'scenario to be calculated requires this key deliverable.
For i = 1 To RiskVectorLength
    If Not IsEmpty(RiskVector.Cells(i, 1).Value) Then

        If RisksPerOutputScenarioMatrix.Cells(i, ColumnIndex).Value = 1 Then
            'Yes, it needs it, so all possible combinations for this output scenario, require this
            'key deliverable, so place a 1 in every key deliverable combination in the matrix
            For j = 1 To UBound(PossibleOutputScenarioVectors, 2)
                PossibleOutputScenarioVectors(i, j) = 1
            Next
        Else
            'the key deliverable is not needed in the output scenario to be calculated
            'so, whether this contains a 0 or a 1, both need to be addressed in this output scenario
```

```
            ReDim      Preserve      PossibleOutputScenarioVectors      (RiskVectorLength,2*
UBound(PossibleOutputScenarioVectors, 2))
          For ArrayCol = 1 To 0.5 * UBound(PossibleOutputScenarioVectors, 2)
             For ArrayRow = 1 To i - 1
           PossibleOutputScenarioVectors(ArrayRow,CInt(0.5*UBound(PossibleOutputScenarioVectors,
           2) + ArrayCol)) = _
                          PossibleOutputScenarioVectors(ArrayRow, ArrayCol)
           Next

             PossibleOutputScenarioVectors(i, ArrayCol) = 1
          Next
        End If
      End If
  Next
```

It is known how many combinations of key deliverables have to be checked on being already
covered by precessor output combinations, so redimension the overlap matrix

```
ReDim ProbabilityNonOverlapWithEarlierScenario(UBound(PossibleOutputScenarioVectors, 2))
For ArrayCol = 1 To UBound(PossibleOutputScenarioVectors, 2)
    ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 1
Next

  For j = 1 To ColumnIndex - 1
     For ArrayCol = 1 To UBound(PossibleOutputScenarioVectors, 2)
```

Only considering output scenarios that are not yet overlapping with previous
output scenarios

```
        If ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 1 Then

             ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 0
             For i = 1 To RiskVectorLength

               If RisksPerOutputScenarioMatrix.Cells(i, j).Value = 1 Then
                  If Not PossibleOutputScenarioVectors(i, ArrayCol) = 1 Then
                              If ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 0 Then
```

```
                    ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 1
                End If
              End If
            End If
          Next
        End If
        Debug.Print ArrayCol, "=", ProbabilityNonOverlapWithEarlierScenario(ArrayCol)
      Next
    Next
```

The calculation of the probability.

For each possible combination of key deliverables in the output scenario where there is no overlap with previous output scenarios calculate the probability for that specific combination of key deliverables.

```
OptionProbability = 0
For ArrayCol = 1 To UBound(PossibleOutputScenarioVectors, 2)


    If ProbabilityNonOverlapWithEarlierScenario(ArrayCol) = 1 Then
       ProbabilityPerVector = 1
       For i = 1 To RiskVectorLength
         If Not IsEmpty(RiskVector.Cells(i, 1).Value) Then
           If PossibleOutputScenarioVectors(i, ArrayCol) = 1 Then
             ProbabilityPerVector = ProbabilityPerVector * RiskVector.Cells(i, 1).Value
           Else
             ProbabilityPerVector = ProbabilityPerVector * (1 - RiskVector.Cells(i, 1).Value)
           End If
         End If
       Next


       OptionProbability = OptionProbability + ProbabilityPerVector
    End If
 Next
   Application.StatusBar = ""
   Application.ScreenUpdating = True
```

```
Exit Function
ErrorExit:
    MsgBox "Error occured, Macro Ended"
    Application.StatusBar = ""
    Application.ScreenUpdating = True
End Function
```

References

Amram, M. and Kulatilaka, N., Real Options, Oxford, 1998

Boer, F Peter., Risk-adjusted Valuation of R&D projects, Research- Technology Management, 2003

Brealey, S. and Myers, R., Principles of Corporate Finance, McGraw Hill, 2002

Cooke, R., Experts in Uncertainty: Opinion and Subjective Probability in Science, Oxford University, 1991

Copeland, T. and Antikarov, V., Real Options, Thomson, 2003

Copeland, T. and Keenan, P., How much is flexibility worth?, The McKinsey Quarterly, 1998 Number 2, pp 38-49

Copeland, T. and Keenan, P., Making real options real, McKinsey Quarterly, 1998

Dalkey, N., The Delphi Method: An experimental study of group opinion, Rand Coporation Santa Monica, 1969

Fabozzi, F. and Mondigliani, F, Capital Markets, Prentice Hall, 2002

Gustafson, D.H., Shukla, R. K., Delbecq, A. and Walster, G. W., A comparative study of differences in subjective likelihood estimates made by Individuals, Interaction groups, Delphi groups and Nominal groups, Organizational behavior and human performance, 1973, pp 280-291

Hampton, J. M., Moore, P. G. and Thomas, H., Subjective Probability and Its Measurement, Journal of the Royal Statistical Society, 1973, pp 21-42

Kahneman, D. and Tversky, A., Subjective probability: A judgment of representativeness, Cognitive psychology, 1972, pp 430-454

Kodukula, P. and Papudesu, C., Project Valuation Using Real Options: A Practitioner's Guide, Ross Publishing, 2006

Lint, O., Retrospective Insights from real options in R&D, working paper 2000, ECIS

Luehrman, T., Investment opportunities as real options: Getting started on the numbers, Harvard Business Review (July-August) 1998, pp 51–67

Margolis, D., Probabilistic Approaches: Scenario Analysis. Decision Trees and Simulations, 2003

Rubenstein, A. and Schroder, H., Managerial differences in assessing probabilities of technical success for R&D projects, Management science, 1977, pp 137-148

Savage, L.J., The foundations of statistics, New York Wiley, 1954

Taylor, D., Berry, P. and Block, C., Does Group Participation When Using Brainstorming Facilitate or Inhibit Creative Thinking?, Administrative Science Quarterly, 1958

Trigeorgis, L., Real options in Capital Investment: Models, Strategies, and Applications,
Praeger Publishers, 1995

Van De Ven, A. and Delbecq, A., Nominal versus Interacting Group Processes for Committee Decision-Making Effectiveness, The Academy of Management Journal, 1971

Van De Ven, A. and Delbecq, A., The Effectiveness of Nominal, Delphi, and Interacting Group Decision Making Processes, The Academy of Management Journal, 1974, pp 605-621

Van Putten, A. and MacMillan, I., Making real options really work, Harvard Business Review, December 2004, pp 134-141

Winkler, R., The Assessment of Prior Distributions in Bayesian Analysis, Journal of the American Statistical Association, 1967, pp 775-800.