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Ort, Datum

Katharina Fodermeyer

"In an era of rapid change, uncertainty is a rule, not an exception!"

(De Meyer et al. 2002)

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I. List of Abbreviations

AHP	Analytic Hierarchy Procedure
CPA	Critical Path Analysis
CSF	Critical Success Factors
DCF	Discounted Cash Flow
DSS	Decision Support System
DTA	Decision Tree Analysis
FMEA	Failure Mode and Effect Analysis
IRR	Internal Rate of Return
NPD	New Product Development
NPV	Net Present Value
PERT	Project Evaluation and Review Technique
PIM	Probability Impact Matrix
PLC	Project Life Cycle
PM	Project Management
R&D	Research and Development
RM	Risk Management
RMP	Risk Management Process
ROI	Return on Investment
VCM	Value Creation Model
WBS	Work Breakdown Schedule

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1. Introduction

Not only since the recent worldwide economic developments – financial and economic crisis – businesses face the challenges of uncertain and volatile future developments. Corporate risk management and contingency planning might attain more attention due to the current conditions and already implemented strategies might now turn to highest priority and prove whether they are sufficient in order to remain competitive or stay in business.

Risk is a phenomenon which is present in every project execution and mainly due to the basic characteristics of projects as complex and unique constructs. Senior management, project managers and team members involved in a project are responsible for understanding involved risks and uncertainties, coping with unexpected turnarounds and providing reasonable and feasible mitigation strategies in order to prevent negative impact on the project outcome. As the most striking risk minimization strategy - not to undertake any project at all - is not a feasible solution for companies in competitive environments, effective and efficient methods need to be implemented to avoid major drawbacks and to exploit opportunities due to uncertain future conditions and occurring risks.

Projects possess three major characteristics, namely finiteness, uniqueness and progressive elaboration, while being constrained in time, budget and resources, exposed to uncertainty and exhibiting interdependencies between projects (Gardiner 2005, Turner/Müller 2003). These features highlight the limited time horizon of projects and the complexity and value creation during the process. Several of the below studied concepts relating to risk management are valid for all types of projects while other methods deal with the specific characteristics of research and development (R&D) projects. Although various project conditions exist, e.g. construction projects, IT projects or software development, the examined project type in this work focuses on R&D and new product development (NPD) projects. A basic characteristic of R&D projects relates to the usually long time frame for investment and implementation which creates high uncertainty concerning the total investment costs. These investments are in the majority of cases irreversible and involve therefore a certain amount of sunk costs. Further, firms undertaking R&D projects face unforeseeable future cash flows resulting from the initial investment and the firms are exposed to the potential, unexpected shutdown of the whole project due to a catastrophic event. (Schwartz/Moon 2000). R&D can be distinguished into basic research, applied research, and experimental research (Coldrick et al. 2002) or basic research, applied research, prototyping and commercial development (Martino 1995). Basic research is conducted when the objective is to generate a general understanding of a certain topic and which might not necessarily result in a specific product. In applied research the product orientation gains more importance while it is still mainly oriented toward the basic understanding. The prototype phase is concerned with whether the intended product can be manufactured and whether a market for the product exists. In the commercial development phase, financial evaluation of the project becomes most important and the product is modified mainly with respect to design and quality. Project goals are not yet defined in a research project, while they are known for development projects (Turner 2005). Independently of the specific kind of R&D or NPD project undertaken by a business, many different uncertainties are present or evolve over the life of the project, which need to be observed and managed during execution by means of risk management techniques.

Project and risk management received increased attention in the past 50 years and - besides the academic research - professional risk management institutes and international associations were founded to provide guidelines and best practices for applications in practice (Hillson/Murray-Webster 2007). Despite intense research and practical suggestions firms still face many difficulties during R&D project management as well as associated with successful completion.

The purpose of the study is to provide a thorough literature review in order to assess the evolution, application and importance of the risk management process during project execution as well as to illustrate recent advances and new insights in this field of research. The overview focuses on major project risks and relevant methods and processes firms can use to avoid negative risk and/or hedge their occurrence, i.e. avoid unintended effects on the project objectives. Hence, the main research question is how the whole concept of risk management contributes to successful R&D projects.

The review includes an assessment of project selection methods in combination with portfolio management. It further covers the steps of the project management process and the related risk management methods. The organizational structure will be examined and how risk management is related to strategy and process flexibility. Finally, performance measures and project success evaluation will be considered.

The structure of the study is as follows. As it is of utmost importance to understand what risk means in order to evaluate strategies to cope with its occurrence, the work starts with an overview of risk and uncertainty definitions. Further, the first paragraph includes a summary and classification of which types of risks may influence R&D projects. Risk exposure, risk attitudes as well as perceptions will also be considered in the first part. The second chapter evaluates which methods for selecting projects and planning portfolios are proposed by the literature. An overview and comparison of various selection techniques as well as involved strategy decisions, constraints and interdependencies will be given. Additionally, the models, included variables and predicted outcomes will be assessed for their contribution to risk reduction and hedging. Following the selection of projects and portfolios, the project management process and the risk management process will be reviewed. Project risk management is an interdisciplinary research topic, encompassing management science, operational research, and psychology and decisions analysis (Williams 1995). The third section describes the steps involved in the overall project management process and how risk management should be integrated, where the processes overlap and complement one another respectively. Proposed and applied techniques and methods within the risk management process are evaluated as well as how multi-project conditions and interdependencies between various projects can be handled. In the fourth chapter, the focus is on organizational prerequisites and influences. It contains an evaluation of how negative risk can be absorbed and positive risk fostered by planning processes and flexibility. Moreover, structural conditions within the organization or firm for successful completion are assessed, as well as the impact of corporate culture on risk management. The final part of the work turns to success measures and treats the question of how success is evaluated and which performance criteria are proposed in the literature. Success factors are reviewed to derive which conditions might cause project failure – or which approaches or processes are most promising to result in project success. The work concludes with an assessment of which methods contribute to successful project risk management and whether it is possible to generalize successful strategies and techniques.

2. Risks in Projects

2.1 Definitions of Risk and Uncertainty

Before analyzing the risk management process and the corresponding methods it is necessary to realize what the concept of risk actually is, which risks exist and how they materialize within a project. Several authors highlight the fact that there is still no consistent understanding or standard definition of the notions of uncertainty and risk in the project risk management literature (Perminova et al 2008, Al Khattab et al. 2007, Hillson/Murray-Webster 2007). Therefore, many authors expand or alter existing definitions with the aim to better understand the basis for risk management.

Studies have shown that managers tend to consider risk as a negative consequence of an event or incidence (March/Shapira 1987, Miller 1990, Gardiner 2005) and that its meaning is related to terms like threat, harm, bad consequences or loss (Al Khattab et al. 2007, Ward/Chapman 2003, Hillson 2002). However, uncertainty as the cause can result in two consequences, namely risk and opportunity, where risk is the "known negative event" and opportunity is the "known positive event" (Permionova et al. 2008). This important discovery that uncertainty about a future state does not necessarily result in a pure negative event is found in various publications (Ward/Chapman 2003, Perminova et al. 2008, Hillson/Murray-Webster 2007, Olsson 2007).

Perminova et al. (2008) make the important contribution of distinguishing uncertainty and risk and explain the two concepts as "cause and consequence". The two terms are often used interchangeably, but are in fact no synonyms. On their search for a common definition, Perminova et al. (2008) consider the interdisciplinary of the topic and compare various risk and uncertainty definitions from different disciplines, i.e. economics, psychology, philosophy, organizational theory, but also from Oxford dictionary and definitions project management associations. The authors finally define uncertainty as a state "when the established facts are questioned", i.e. when no measures of the event occurring can be derived and when the incidence is not imagined to happen. A more detailed distinction of uncertainty involves known unknowns, where the event can be identified to a certain extend, and unknown unknowns, where no knowledge or qualitative evaluation is possible (Ward/Chapman 2003), and the events are not explicitly known (Chapman/Ward 2004). De Meyer et al. (2002) define four classes of uncertainty as variation, foreseen uncertainty, unforeseen uncertainty and chaos. Variation occurs when the consequences of actions, triggered by small influences, take values within a certain, known magnitude. Foreseen uncertainties can be identified and actions can be taken to manage them. The unforeseen uncertainties are comparable to unknown unknowns and represent initially unidentifiable occurrences, which "can arise from the unanticipated interaction of many events" (De Meyer et al. 2002). The category of chaos contains conditions when no structure in the project exists and even the purpose or outcome is uncertain from the very beginning. Further, the authors propose to subjectively classify different project activities of possible incidences into an "uncertainty profile", representing the four distinct types mentioned above.

Ward/Chapman (2003) even question the term "risk management" and recommend renaming the discipline into "uncertainty management", encompassing all possible consequences of uncertainty. As mentioned above, the authors criticize that project risk management is mentally related to the down-side, negative risk or threat while neglecting the potentials for up-side, positive effects of uncertainty, namely opportunities. They define five areas of uncertainty encompassing *variability* of performance estimates (time, cost, quality) but also *ambiguity* due to uncertainty about the basis of estimates, about design and logistics, about objectives and priorities and about fundamental relationships between project parties.

The two key attributes of variability and ambiguity are important to consider when facing uncertainty (Hillson/Murray-Webster 2007). Variability represents future uncertainty as a range of possible outcomes and is in the literature also referred to as *aleatoric probability* – corresponding to the Latin word alea, a game with dice involving chance (Williams 1995). Ambiguity or *epistemic uncertainty* is defined as an event where no probability can be derived, and where the whole situation or a single aspect is uncertain, vague, or not fully understood. This aspect can be defined as "uncertainty of meaning" (Hillson/Murray-Webster 2007).

Definitions of risk consider situations where at least probabilities of future events can be derived or when there are "repetition and replicability" (Pender 2001). Risk is an imaginable event which can be calculated and controlled to a certain extent as some knowledge about the situation is available (Perminova et al. 2008). It can also be conceptualized as the combined effect of probability and consequence of an event

(Al Khattab et al. 2007), as impact and likelihood (Williams 1995), as variability of project parameters (Elmaghraby 2005), or as the inability to predict the outcome variables (Miller 1990). Gardiner (2005) distinguishes between *speculative risk* where both a positive and a negative outcome is possible and which is mostly present in projects, and *pure risk* which incorporates only the downside potential but which can normally be secured by insurances. The former can also be called *business risk* (Turner 2005) or *symmetric risk* (Holt 2004). Pure risk on the other hand is also known as *insurable risk* (Turner 2005) or *asymmetric risk* (Holt 2004). Risks are present in all projects and exhibit certain characteristics which involve that they change over time, they concern a future occurrence, and, although they are unknown to some extent, strategies exist to modify their impact (Gardinier 2005).

The existing definitions of risk and uncertainty show clearly that the concepts overlap to a certain extent and that it remains difficult to find an all-encompassing unique wording. However, an important conclusion is that the two terms do not represent the same, rather are cause and consequence of an event, and as Hillson/Murray-Webster (2007) but it simply "risk is uncertainty that matters", emphasizing that risk is always related to consequences on project objectives.

The probably most important recent contribution is the inclusion of opportunities as possible consequences of uncertainties, surmounting the traditional view of risk as purely negative impact on objectives. Risk definitions in publications until mid of the nineties focused on the negative aspect of risk, while up to the new millennium neutrality in defining risk was predominant and as of the year 2000 most of the literature adopted the view of explicitly incorporating opportunities, additional to threats (Hillson/Murray-Webster 2007).

2.2 Sources / Classification of Risk and Uncertainty

2.2.1 Internal vs. External

Sources of risk are important to discover and realize in order to assess the project conditions and to create the base for the risk management process. As the distinction between internal / external risk and uncertainty (Miller 1990, Elmaghraby 2005, Perminova et al. 2008) shows, sources of risk can evolve from situations intrinsic to the firm, or alternatively from environmental factors. Uncertainty from internal sources is systematic uncertainty, arising from system complexity, while external uncertainty is considered as contextual uncertainty, stemming from the project environment and which needs to be managed with an intuitive process (Perminova et al. 2008). Nevertheless, it is of high importance to consider and manage the various interrelations between different uncertainties in order to formulate strategic responses and adopt the exposure to the various sources of uncertainty in a way to fulfill corporate performance criteria (Miller 1990). This is mainly of importance as due to existing interrelations trade-offs between individual uncertainty characteristics are common. These trade-offs can result in a higher exposure to a certain source of uncertainty, while trying to decrease the effect of another (Miller 1990). Gardiner (2005) classifies risk sources into three distinct categories. The first source concerns variables which are under project control. These factors are known or discovered by the team and can be managed. The second category contains variables which are not under direct control of the project team as they occur in the external environment. Still, management of these factors by institutions is possible as they include for example government policies. Risk sources in the third category are not controllable and include natural catastrophes but also political instability, terrorism or world prices.

A very detailed overview and classification of risk sources is provided by Miller (1990) who distinguishes three types of uncertain variables: general environment, industry and firm-specific. These three interdependent sources all contribute to the overall project risks (see Figure 1). While the first two relate to external uncertainty, the firm-specific variables exclusively cover issues within the corporation, i.e. internal uncertainty.

2.2.2 General Environment

Miller's (1990) first category of general environmental variables cover factors beyond a certain industry, and includes natural, social, macroeconomic, government policy and political uncertainty. Within each of these five main uncertainties, specific events might cause or enhance the exposure of a firm. Natural uncertainties contain weather conditions as well as natural disasters which generally can be neglected for R&D projects. Social uncertainty is closely related to politic and policy uncertainty as it encompasses general social turmoil, riot and terrorism. Macroeconomic indicators of uncertainty are for example inflation, interest rates and exchange rates, while policy uncertainty is characterized by trade restrictions or barriers, price controls or fiscal reforms. Policy changes concerning patents or technology standards and regulations are important to consider for R&D projects, as they influence whether future business can be sustained (McGrath/MacMillan 2000). The category of political uncertainty covers war, revolutions or democratic changes. Emphasis is put on the fact that the general environmental conditions might not be restricted to single countries, but might have consequences for other nations as well due to international interdependences (Miller 1990). Policy and political uncertainty are also referred to more generically as institutional risks (Miller/Lessard 2001). Al Khattab et al. (2007) classify the general risks of international business into four categories: natural, cultural, financial and political risk. For Kattab et al. (2007) political risk incorporates legal and societal sources, and can be further differentiated into host-government risk, host-society risk and interstate risk.

2.2.3 Industry-Specific Factors

The second category of Miller (1990) applies to industry-specific factors, distinguished into input market, product market and competitive uncertainty. While input market uncertainty is concerned with the supply side and acquisition of appropriate production resources, product market uncertainty deals with the demand for the output. Competitive uncertainty is increasing in its importance mainly due to globally competing firms, various entrants and the difficulty to attain and keep competitive advantages (Willigers/Hansen 2008). The competitive situation is heavily influenced by governmental policies and regulations, as for example in the pharmaceutical industry patent regulations create more dynamic structures (Hartmann/Hassan 2006). According to Miller (1990) technological uncertainty about product and process innovations is part of the competitive uncertainty. Uncertainty in R&D projects can also be classified into technical and target uncertainty (Martino 1995). Target uncertainty is concerned with market orientation and customer acceptability and occurs for R&D prototyping and commercial research. Technical uncertainty on the other hand is mainly involved in basic and applied research when uncovering the general technical feasibility of a vague idea. Technical uncertainty is part of completion risk which further involves operational risk (Müller/Lessard 2001). For corporate strategy considerations concerning project portfolio compositions the main distinction between technological and market uncertainty contributes to the general selection process (MacMillan/McGrath 2002). The consideration of technological uncertainty within the project selection process will be examined in chapter 3.

2.2.4 Firm-Specific Factors

The third group according to Miller (1990) relates to firm-specific uncertainties which involve: credit, R&D, operating, liability and behavioral uncertainties. Credit uncertainty deals with uncollectible loans. The very general category of R&D uncertainty covers all issues regarding the timeframe, investment and result of the R&D activity. This category can obviously not be seen as purely firm-specific but needs to be considered in a broader sense and is closely related to technology uncertainty described in the previous section. Operating uncertainties encompass three sub-categories relating to 1) employees' safety, productivity changes and strikes, 2) shortages of raw materials or quality differences and 3) production-related uncertainty, e.g. machine breakdown. The liability uncertainties involve the consumption of the product and emissions, which in turn is interrelated to governmental policies as well as the political environment. Finally, the category of behavioral factors treats principal-agent conditions and opportunistic behavior. Opposing goals lead to moral hazard problems, and the shift of power from the principal to the agent (project manager) due to asymmetric knowledge about the project itself result in adverse selection problems (Atkinson et al. 2006). These principal-agent relationships create additional costs and enhance uncertainties (Turner/Müller 2003). Jensen et al. (2006) introduced "interactional uncertainty" as a combination of vertical uncertainties, i.e. principal-agent relationships and horizontal uncertainties, i.e. interactions on the same operational level.

Further categories which can be included to the group of firm-specific sources are risks and uncertainties related to scope/change management, project, project management and strategy (Royer 2000). The project contains the risk of time and complexity uncertainty, while project management itself might bear the uncertainty about whether the implemented process works and supports the specific objectives (Turner 2005). This can also be referred to as process risks (Ward/Chapman 1995). Closely related to process risks are human errors which must also be considered as an important risk source. Human errors occur when wrong decisions are taken during the process (Wu et al. 2006). Further intangible sources of uncertainty are workforce productivity and fluctuation as well as uncertainty about existing knowledge and skills (Bräutigam et al. 2003).

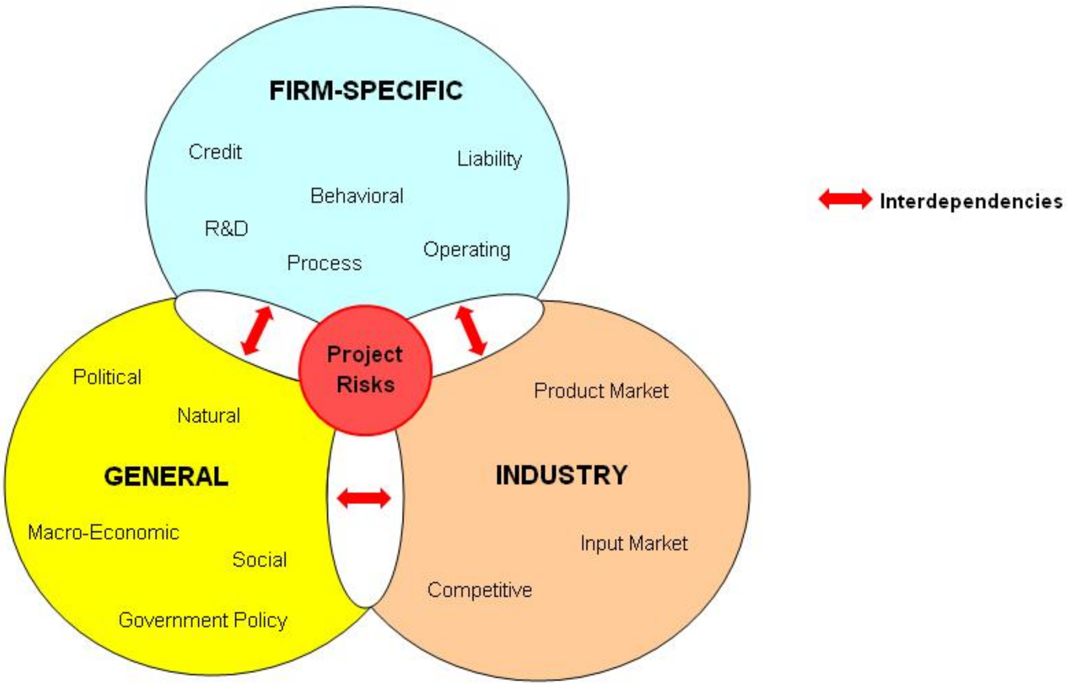

Figure 1: Uncertainty sources and interdependencies

2.3 Risk Attitude and Perception

After having examined the definitions of risk and uncertainty as well as the various sources of risk, it is now necessary to turn the view to the people involved, their behaviors and attitudes and the resulting perceptions about risk in projects. People manage the process, contribute to the project progress, conduct risk management and interact with the various interfaces. Therefore, it is important to study and understand how they perceive different situations, and how attitudes are built or influenced, e.g. by varying environmental effects (March/Shapira 1987).

Generally, many different individuals and groups within the company as well as from the external surrounding are involved in accomplishing R&D projects, e.g. senior management, project managers, team members, stakeholders (e.g. external agents, customers). All these parties might have different attitudes about risk and/or possess different perceptions about the importance or severity of a certain uncertainty (Perminova et al. 2008). This "tendency to optimism or pessimism" can also be seen as bias towards assumptions (Chapman/Ward 2004). In their study Camprieu et al. (2007) evaluated that people in different countries (studied countries were China and Canada) possess different perceptions about project risks and that project managers with different cultural backgrounds weigh the importance of certain risk categories of a complex project differently. Further, within one country the perceptions of managers with regard to external uncertainties can differ, resulting in heterogeneous perceptions of individuals within one country, industry, or firm (Miller 1990).

Although perception contributes to a large extent to the individuals' view of a risky situation, the basic attitude towards uncertainty does also play an important role. Hillson/Murray-Webster (2007) define risk attitude as "a chosen state of mind with regard to those uncertainties that could have a positive or negative effect on objectives, driven by perception". Attitudes represent situational responses driving behavior depending on the perceived environment or event and are highly subjective. As the behavior is derived from a certain perception, the risk attitude of a single person or group can also vary in different situations. When for example the overall situation is already in a bad state, more risk is taken whereas managers who are already above a set target tend to avoid risk (March/Shapira 1987). A classification of risk attitudes on a range from very uncomfortable with uncertainty to very comfortable with uncertainty yields to the following six risk attitudes as described by Hillson/Murray-Webster (2007):

The most uncomfortable feeling towards risk have people who are *risk paranoid* as they possess an extreme discomfort level with uncertainty or are almost paralyzed when uncertainty occurs. The next category is *risk aversion*. Risk averse people fear risk and try to avoid the situation. They prefer security and tend to overemphasis on threats and strategies to cope with them. This behavior can be seen as a "basic survival instinct" (Royer 2000). On the other hand this attitude might under-evaluate opportunities resulting in the risk of missing some important chances while reacting too aggressively towards threats (McGrew/Bilotta 2000). Moreover, risk aversion has an impact on the technology choice for uncertainty reduction as shown by Krishnan/Bhattacharya (2002).

According to Hillson/Murray-Webster (2007) *risk tolerance* leads people to accept risks as a "normal part of live" or business. Although this definition appears as a desirable state, the drawback with risk tolerant behavior is that people might not recognize the severity of a situation, which can result in no proactive action facing risks - both threats and opportunities. Therefore, risk tolerant persons or groups tend to manage risks inappropriately. This attitude can lead to more reactive actions for occurring threats being necessary, or in the (too) late recognition of opportunities. *Risk neutral* behavior is characterized by a focus on the long-term benefits of an action. People who are risk neutral have no strong tendency towards aversion or seeking in short-term, however are prepared and willing to bear a risk if the expected future benefits are worth it. Risk neutrality is generally the attitude which is assumed as the behavior for firms in real option models (Luo et al. 2008). People or groups who are r*isk seeking* are eager to challenge risks and do not show fear facing uncertain situations. Opposite to risk aversion, risk seekers tend to downplay threats while focusing too much or overemphasizing opportunities. This attitude can therefore lead to accepting threats and chasing all possible opportunities with the aim to get all benefits from them. The category opposite to risk paranoia is *risk addiction* and describes people or groups who are extremely comfortable with uncertainty. Risk addicted persons are highly seeking all risks (Hillson/Murray-Webster 2007).

Although groups or individuals within firms or projects can have very distinct and unique risk attitudes there are various factors or situational influences which can change or shift the initial risk attitude (March/Shapira 1987). Influences shifting to the risk-seeking range encompass high levels of skill, knowledge or expertise, high perceived control, low perceived probability of impact, if the risk is temporally far away and if the chance for direct consequences is low (see Figure 2). Accordingly, the shift towards risk aversion occurs if the mentioned conditions are reversed.

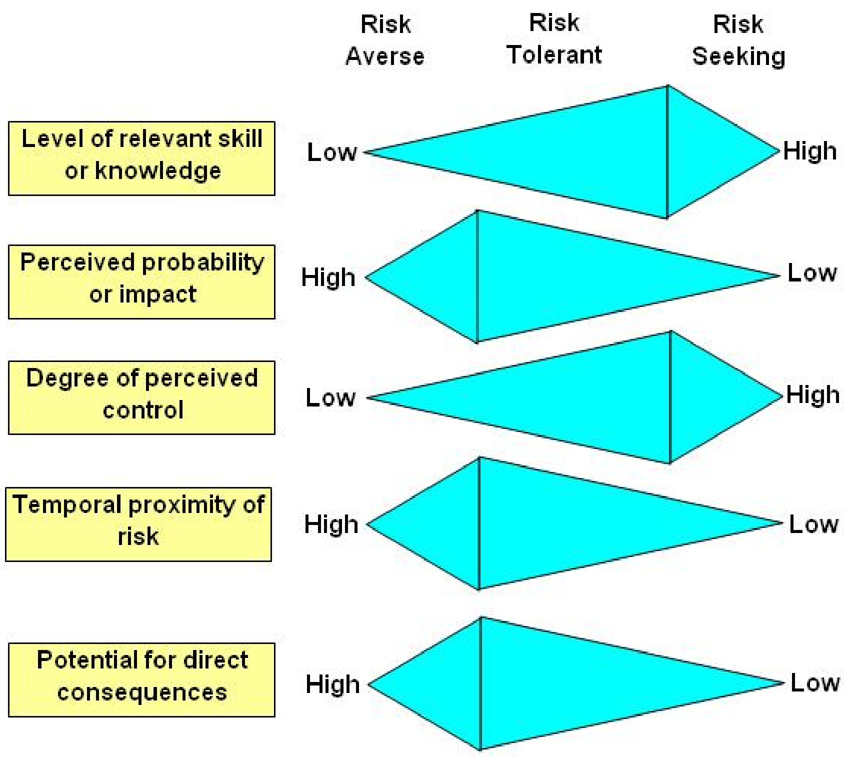

Figure 2: Situational factors on risk attitude (based on Hillson/Murray-Webster, 2007)

A further factor which impacts the perception of risk and uncertainty is the nation the company is doing its business in (Hillson/Murray-Webster 2007). The most well known study on culture characteristics across different nations was conducted by Hofstede, studying IBM employees in different countries. One of the Hofstede dimensions is *uncertainty avoidance* which is described as the degree of comfort in uncertain situations. Nations with a low uncertainty avoidance score tend to a behavior of acceptance of uncertainty but also put a low value on certainty whereas a high uncertainty avoidance value describes countries where people try to reduce uncertainty and minimize exposure to uncertainty (Camprieu et al. 2007, Hillson/Murray-Webster 2007). Although the Hofstede uncertainty avoidance index supports the thesis that people in different cultures have different perceptions about project risk (Camprieu et al. 2007), the index results cannot derive or generalize risk aversion for high values and risk seeking for a low uncertainty avoidance ranking (Hillson/Murray-Webster 2007).

The above described risk attitudes prove that individual managers or firms might evaluate risks and react quite differently when facing risky situations (McGrew/Bilotta 2000, Perminova et al. 2008). The expected utility of actions and the overall risk tolerance of organizations in high risk environments lead to a certain behavior. The risk attitude and overall risk tolerance level towards a specific project situation impact clearly managerial behavior as well as the proceeding during the project management process (Piney 2003). Understanding the basic attitudes is very important for researchers although they neither may be able to find out the risk attitude of single respondents in project situations nor uncover the complete situational influences the respondent is influenced by (March/Shapira 1987). Nevertheless, the underlying risk attitude affects the behavior in risky situations in practice, the decision making process, as well as the actions which are considered and implemented (Piney 2003).

3. Project and Portfolio Selection

3.1 Main Trade-offs and Interdependencies

Before investigating the project and risk management process in detail, the following section describes the techniques, strategies, difficulties and trade-offs for a company when selecting projects and composing portfolios. The project a firm chooses to implement should be aligned to the firm's overall long-term R&D strategy (Henriksen/Traynor 1999). The selection of the "best", most suitable or optimal projects for a balanced portfolio is necessary to guarantee future business (Meredith/Mantel 1989) and maximize the benefit to the organization (Martino 1995), but poses a challenge to most firms as several different criteria and contradictory objectives need to be considered (Ghasemzadeh et al. 1999). A high amount of risk is involved in the selection of projects as the finally chosen projects result in investment commitments (Gardiner 2005). Firms can hedge the investment risk for highly uncertain R&D projects by investing successively in different options and composing portfolios of projects with varying degrees of risk (MacMillan/McGrath 2002). The selection process itself involves estimates about potential projects, e.g. concerning project costs, which constitutes the risk of wrong assumptions. Further, interdependencies between projects might exist and are important to consider during the selection process. Zuluaga et al. (2007) distinguish between resource, benefit and technical interdependencies (see also Fox et al. 1984). Resource interdependency is present when fewer resources are needed for accomplishing a set of projects simultaneously or when certain resources or equipment are used for more projects. Benefit interdependencies can either result in complementary projects, where the joint pay-offs exceed the benefit of a single project, or on the other hand lead to competitive projects, where lower overall benefits arise due to cannibalization between projects. Thirdly, technical interdependencies occur if from mutually exclusive projects only one can be selected or if for contingent projects one is chosen if all others are selected as well.

As no firm possesses unlimited resources the available budget, workforce and equipment need to be allocated to individual projects and the best timing to start new projects need to be ascertained. The restrictions in project resources create trade-offs and "battle for resources" (Blichfeldt/Eskerod 2008), which need to be managed in order to find the optimal amount and sequence of projects to conduct. Probably the most striking trade-off in project and portfolio selection is between risk and return (Jafarizadeh/Ramazani 2008).

If a company fails to select the optimal projects, the consequences are on the one hand resources and therefore costs spent on the wrong project with no benefit for the firm, and on the other hand occurring opportunity costs, as these resources could have been more profitably assigned to other projects (Cooper/Edgett 2003). The challenge is "first, to select projects that will be technically successful, have significant impact, and bring the organization great rewards, and second, to not overlook such a project when it is one of the choices" (Henriksen/Traynor 1999). However, technologically uncertain projects should be part of an organization's project pool, as these can ensure future competitive advantages (MacMillan/McGrath 2002).

3.2 Project Selection Methods

In order to evaluate the best projects to select, the literature provides various methods and models considering qualitative and/or quantitative criteria (Henriksen/Traynor 1999). Souder (1972) discovered that important factors for the choice are that the selection model is realistic, capable to help in optimizing a decision, flexible and easy to use as well as implementable at reasonable costs. In his early review on R&D project selection methods Baker/Freeland (1975) listed several limitations of the models existing at that time, basically an insufficient consideration of risk and uncertainty, of interrelations between criteria and of interdependent projects. As research discovered little utilization of R&D selection models in practice due to inflexibility in application and unrealistic assumptions (Martino 1995), as well as ineffective results (Cooper et al. 2000), especially for early, static selection techniques which did not incorporate the organizational decision process (Schmidt/Freeland 1992) or were too inflexible for varying corporate environments (Mandakovic/Souder 1985), continuous improvement and adaptation of selection methods is still ongoing.

A basic difficulty of the selection process of R&D projects is that prospect projects differ to a large extent in their underlying characteristics and a certain measuring method used might not cover an important metric of an in fact very promising project (Linton et al. 2002). Therefore, more recently, proposals of using a hybrid approach which includes different techniques (Cooper et al. 1998) or flexible selection methods (Henriksen 1999) gained more importance. The selection methods for R&D projects need to consider the interaction with corporate strategy objectives (Schmidt/Freeland 1992) and organizational domains (Tian et al. 2002). Finally, project portfolio management should go beyond models and tools and include the overall managerial perspective (Blichfeldt/Eskerod 2008), prioritize projects and match the portfolio mix to the overall business strategy (Cooper/Edgett 2003). The next paragraphs give an overview on existing selection methods, simpler techniques which might be applicable for lower risk projects, as well as combined and hybrid methods, and finally techniques for the optimal portfolio composition.

3.2.1 Non-numeric, Ranking and Scoring Methods

The simplest form of selection takes place when a project is proposed by senior management who considers it as a "sacred cow", when the project is absolutely necessary for being able to further operate or in order to remain a competitive position (Meredith/Mantel 1989). All these conditions do not require any immediate further consideration and do not really select a certain project as there is no feasible other solution than starting the project. The next category does involve ranking of projects which is mostly a subjective judgment of project characteristics but nevertheless can give important insights and provide a general view on potential available projects. Pure ranking is reached for example by the Q-Sort model (Meredith/Mantel 1989), which orders potential projects according priority descending from best to worst. Similar to this model and involving preferences is pairwise comparison according different criteria. A ranked list is created from the result of all comparisons between the various pairs (Martino 1995). Techniques which are easy to use and understand but still represent relative measures, and do not cope for interdependence between evaluation criteria, are scoring techniques. The unweighted 0-1 factor model, unweighted factor scoring model and weighted factor scoring model are methods in this category (Meredith/Mantel 1989). While in all these scoring models projects are evaluated whether they fulfill a defined criterion, the first method does simply count how many criteria are met by the projects and does – as a major drawback - assume that all factors are equally important. The unweighted factor scoring model uses a scale for the assessment as to how much each criterion is met by a certain project. Finally, the weighted factor scoring model assigns weights to the decision criteria which are multiplied by the score. A major limitation of this method is that it is not applicable for a large amount of evaluation factors (Meredith/Mantel 1989). A further technique to assign scores to projects is the analytic hierarchy procedure (AHP), which first creates a hierarchy of the criteria by decomposing it into sub-categories and assigns then ranks to the individual projects under evaluation, using pairwise comparison (Martino 1995). Scoring techniques are suitable methods for R&D project selection as the data requires not too much detail, involves qualitative measures, is easy to use, and the criteria list can be adjusted to the companies' specific needs (Henriksen/Traynor 1999).

3.2.2 Financial Methods

Another broad category of selection techniques are financial or economic models. Very simple approaches of financial models are the calculation of the payback period which is the amount of investment divided by the expected yearly cash return or average rate of return where annual profits are divided by the total investment (Meredith/Mantel 1989), or the discounted payback technique calculating with discounted cash flows. Nevertheless it still neglects any cash flows after the initial investment is covered (Gardiner 2005). The probably most known economic model is calculating the net present value (NPV) of an investment. This technique discounts the cash streams in each period with a discount rate to the present value and compares this value with the initial investment. If the NPV yields a positive value the project is selected. Quite similar to NPV and also a discounted cash flow (DCF) technique is the internal rate of return (IRR) which calculates the required rate of return to equal present values of cash out- and inflows. In the same category of DCF exists as well the profitability index (PI), also called present value index or benefit-cost-ratio, which is calculated as the NPV of future expected cash flows divided by the investment costs (Gardiner 2005, Meredith/Mantel 1989). If a single project is considered, a PI of more than 1 yields to selecting the project.

NPV methods are simple to use and understand, but have drawbacks which question their use as a (single) decision criterion for project selection. First of all, NPV is biased towards the short run (Meredith/Mantel 1989) and does not take into account resource constraints which are important to consider for portfolio decisions (Cooper 2000). NPV calculations require data about future cash streams which might be difficult to evaluate or only represent a "best guess", especially early in the project (Cooper 2000). Moreover, the evaluation always uses the same discount rate in all periods which might not represent reality correctly (Martino 1995). For a complete evaluation of the project, the discount rates of a DCF method would need to be adjusted to the respective business case and consider different rates in each phase (Faulkner 1996).

Decision theory models or decision tree analysis (DTA) are another possibility to help with project selection decisions as they show the subsequent alternatives which are present in various stages of the possible alternatives (Gardiner 2005). At each stage or decision node two or more new alternatives with a certain probability and outcome are possible. The structure and interdependence of these subsequent decisions is visualized with a decision tree and the expected values or pay-offs for the considered options can be calculated by multiplying with the probability of the individual branch (Martino 1995). The optimal choice with maximum expected NPV is calculated by starting at the end-branches and rolling-back to the initial node. Additionally, DTA can incorporate the managerial decision of later abandonment of the selected project. However, as with static NPV calculations, selecting the correct discount-rates for the stages, which appropriately represent the respective risk level remains the major challenge (Trigeorgis 1996).

Despite the stated drawbacks, DCF techniques, usage of hurdle rates (NPV or IRR), and profitability indexes lead not necessarily to a wrong decision and even come close to optimal decisions (McDonald 2000). Liberatore/Titus (1983) found that financial models are heavily used in R&D project selection with NPV/IRR as the category which was most commonly applied by firms, mostly for development projects in the commercialization phase whereas for new product R&D or exploratory research also informal models are used. This result is supported by a recent survey on methods used in pharmaceutical R&D where as well DCF and NPV methods are preferred (Hartmann/Hassan 2006).

Though they are heavily used, the inadequacy of quantitative selection tools like NPV, and expected sales as well as qualitative factors like expected risk level for new technology development projects is highlighted by Cooper (2006). As he puts it: "Don't use traditional methods for non-traditional projects". While the methods are focused on the short-term and require quite concrete data, some projects involve too much uncertainty and risk to provide the required input or to survive the selection process. The data which is available at the start of a technology development project is too vague and still undefined and if used for selecting projects exclusively with financial methods the overall portfolio will be of low value. Schmidt/Freeland (1992) who distinguish between "decision event" models which comprise the traditional methods focusing on maximization of a single objective and "decision process" methods, highlight that decision event models are not suitable for R&D projects with high uncertainty. As financial methods oversimplify the evaluated projects, qualitative metrics are very important to consider additionally in order to comprising all aspects of potential R&D projects and to reach finally optimal portfolios (Linton et al. 2002).

3.3 Portfolio Selection and Optimization

3.3.1 Project Interdependencies and Risk Exposure

For the purpose of portfolio optimization, accounting for interdependencies between prospect projects and diverse resource constraints, mathematical programming is used for selection decisions (Martino 1995). With the growing complexity and increased number of restrictions and conditions to be included in the models, multi-criteria decision methods and programming methods (linear, integer, dynamic, or goal programming) for the optimization of the selection decision were proposed by researchers (Sefair/Medaglia 2005, Zuluaga et al. 2007). These models optimize the project's or portfolio's NPV but consider explicitly different side conditions like available resources or optimal scheduling of more projects as well as interdependencies. A mixed-integer programming model for project selection and scheduling of interdependent projects maximizing the NPV of the portfolio showed that interdependencies impact the number of selected projects in the optimal portfolio as well as the sequence of projects (Zuluaga et al. 2007). The model developed by Sefair/Medaglia (2005) optimizes selection and scheduling using profitability (maximizing NPV) and risk (minimizing variance of NPV) in the objective functions, satisfying constraints in start dates and budget. Their results show that relaxing assumptions and allowing for marginal changes, e.g. in start dates, does have consequences on the effective sequence, resource allocation and risk level of the portfolio.

As the projects in a portfolio all bear specific risks it is important to integrate a measure for the overall portfolio risk (Ringuest et al. 1999). Risk mitigation and diversification therefore are to be considered whenever projects are added to an existing portfolio or a new portfolio is created. Ringuest et al. (1999) propose a method using risk-adjusted return which evaluates every single project in the overall context of all projects. A model which considers risk in a portfolio of projects was also developed by Graves et al. (2000). Similar to Ringuest et al. (1999), the authors realized that existing models are not really adopted by managers as these are mostly too complicated, require data which is definitely not available for R&D projects at the moment of selection or do not lead to optimal portfolios. The objective of the model by Graves et al. (2000) is minimization of portfolio risk for a certain level of financial return, i.e. with inputs for the probability of success for the various projects and the corresponding return rates if the project is successful or fails the model plots all efficient portfolios in a diagram which can be further evaluated. The model covers risk mitigation, but unfortunately does not consider any other interrelations between projects.

Graphical methods gain further attention as they provide a means of decision support which is easier to understand than lists of data or complex mathematical models (Linton et al. 2002). Instead of resulting in a ranked list of projects of a portfolio, Jafarizadeh/Ramazani (2008) propose an "efficient space" for portfolio selection which is derived from the firm's equity market line, its highest risk tolerance level and the marginal cost of capital. Popular graphical techniques in practice are bubble diagrams or portfolio maps which depict projects in a two-dimensional space according to various criteria, e.g. risk vs. reward, technical feasibility vs. market attractiveness or competitive position vs. project attractiveness (Cooper et al. 1998). Although these maps provide a good support to selection decisions as they can incorporate strategic objectives, this method is not applicable for a large amount of prospect projects. Further, these diagrams neglect resource constraints (Cooper et al. 1998) and do not display the risk mitigation occurring in the portfolio (Ringuest et al. 1999). Consequently, the joint use of an objective multi-criteria decision tool and a quite subjective graphical method might yield more meaningful results (Linton et al. 2002). Their proposed objective method is a data envelopment analysis (DEA) while the subjective evaluation is conducted with a value creation model (VCM). DEA is a ranking method measuring the relative efficiency of projects and creating an efficient frontier. The technique incorporates multiple criteria – qualitative (stage in lifecycle, intellectual property, market data) and quantitative (investment, cash flows) - and is especially applicable for very uncertain situations. It is used to reduce the number of projects for further consideration by prioritizing the ranked list of projects into high, low and intermediate. In the second step the group of intermediate projects are considered further while those ranked high are accepted and those ranked low are declined. The VCM plots the remaining projects graphically using various dimensions and depicting as well interrelationships. These graphics can then be evaluated more thoroughly in order to decide which projects to select. Later, Linton et al. (2007) expanded the DEA being able to compare and rank every project in a group (high-low-intermediate) to all others, achieving a relative attractiveness ranking within the portfolio.

3.3.2 Strategy and Portfolio Balance

Studying the performance differences of portfolio management techniques, Cooper et al. (1998) revealed factors which distinguish top from poor performing companies. The main difficulties exist in achieving the right number of projects for limited resources and in achieving a balanced portfolio, i.e. with short-term and long-term projects and different risk level projects. This involves as well that companies choose "fewer but better projects" (Cooper/Edgett 2003). Moreover, McDonough/Spital (2003) state that "portfolios that best meet their objectives include a higher proportion of uncertain projects" and additionally conduct more portfolio reviews. Better performers in the study by Cooper et al. (1998) are mostly using a formal system for managing their portfolios but one which is seldom based on a unique financial method but instead based on the business strategy as source for resource allocation to different projects. Cooper et al. (1998) unveils as the major drawbacks of financial methods for portfolio management that they are not effective and can result in actually wrong decisions, that they do not create balanced portfolios and that they cannot allocate the correct number of projects for the existing resources. The "resource crunch", i.e. too many projects for too less people or a lack in focus on specific NPD projects, is among the main weaknesses of NPD project execution (Cooper/Edgett 2003). Due to resource insufficiencies the quality of project activities decreases and important actions or steps are not done or fulfilled. All these occurrences lead to an overall low project performance or even failure. Firms aiming at a balanced, successful portfolio of projects should use various criteria in making selection decisions and to reach this, a "hierarchical approach" or hybrid approach is proposed, combining various methods to result in the best, balanced portfolio (Cooper et al. 1998). Moreover, possible options with respect to different conditions in the market and technology environment need to be considered and classified into the portfolio (McGrath/MacMillan 2000). As a selection technique should encompass the evaluation of the single projects and the selection of those projects to include into the portfolio while being applicable to the type of research conducted by the company, a composite approach or multi-attribute technique is a promising solution for "logical" selection decisions (Coldrick et al. 2002).

Decision support systems (DSS) are incorporating the flexibility and hybrid approaches mentioned above in the R&D project selection process by providing computer-aided and easy-to-use systems. They allow decision makers via a user interface to modify portfolio data which will then be processed by different mathematical models, e.g. DSS can incorporate AHP and a programming model (Ghasemzadeh et al. 1999), a customized multi-criteria decision model (Stewart 1991) or a scoring algorithm for project ranking (Henriksen/Traynor 1999). DSS show how slight changes in specific parameters can affect the overall portfolio. The most important aspect of a DSS is its interactive nature. Decision makers can quite easily change parameters, e.g. resources available, add mandatory projects or re-evaluate for changing situations (Stewart 1991). The approach proposed by Ghasemzadeh et al. (1999) incorporates three steps in the portfolio optimization. The process starts with an AHP or weighted scoring process in order to reduce the involved criteria, followed by a 0-1 integer linear program which maximizes the portfolio benefit and accounts for resource constraints, interdependencies and scheduling of projects as well as mutual exclusive, mandatory or ongoing projects. The third step involves the "balancing" of the portfolio by the decision makers and adjusting for risk. Kira et al. (1999) distinguish a deterministic, probabilistic and informational phase within the DSS. While the deterministic phase involves gathering of general performance and environmental data concerning for example project benefits, costs, resource efforts etc., the probabilistic phase generates a risk estimate. Finally, in the informational phase adjustments of certain parameters can be made in order to decrease uncertainty. Tian et al. (2002) developed an organizational decision support system for R&D project selection focusing on the organization and group decision making and assigning different usage rights for the system and coordinating group interactions. All these approaches incorporate some form of basic evaluation of projects with final adjustments made by the decision makers to fit the model outcomes to the firm's strategy.

It became more and more important to create a method which is flexible enough to be customized to a certain firm's requirements while at the same time being manager-friendly, easy to use, sophisticated, encompassing all relevant constraints, uncertainties and interrelationships and still resulting in the best portfolio of R&D projects (Graves et al. 2000). The development towards hybrid or combined selection systems can exploit the advantages of various single methods, incorporating more advanced mathematical techniques, non-measurable criteria as well as graphical presentation. Firms still rely heavily on their financial figures and performance (Cooper et al. 1998) – but the involvement of several qualitative and maybe more subjective criteria remains important as these might better represent strategy considerations and project features immeasurable in economic terms (Ghasemzadeh et al. 1999). A company needs to choose the combination of methods which best fits to their requirements and which creates portfolios according to their individual conditions and strategy targets. A mix of various project selection techniques resulting in differing illustrative representations encompassing the various aspects of the possible portfolios might also prove advantageous for the different groups involved in and responsible for the selection process (Linton et al. 2002).

Overall, organizations must be able to discover growth potentials of high risk projects which might not produce immediate cash inflows (Mitchell/Hamilton 2007). These growth options are strategically important future opportunities where an early investment results in a profitable future business (Trigeorgis 1996). McDonough/Spital (2003) discovered that successful portfolios had fewer projects of low technical and market uncertainty in their portfolio as higher benefits are only achieved with a balanced portfolio. For R&D project selection decisions, real option assessment explicitly reveals the rewards of high risk projects, while DCF techniques seem to under-evaluate the future pay-off of basic research projects as they exhibit a bias towards short-term and lower risk activities (Boer 2002, Pennings/Lint 1997). Mitchell/Hamilton (2007) highlight the trade-off between shorter project life cycles (PLC), i.e. faster product development, and long-term basic research needs, which poses challenges for strategies aimed at creating optimal portfolios and the appropriate financial assessments. They distinguish between business investment, strategic positioning and knowledge building. As business investments are merely development activities where uncertainty is relatively low, DCF methods like return-on-investment (ROI) are appropriate for financial evaluation. On the other hand, knowledge building activities like exploratory research are very vaguely defined and should be treated as "a cost of doing business". In between these two extremes are strategic positioning projects where neither investment evaluation with ROI nor treatment as pure overhead costs should be applied. In order to evaluate these projects appropriately, according to Mitchell/Hamilton (2007) strategic option analysis is the best solution. This shows clearly that not for all kinds of R&D projects the "classical" assessment techniques are inappropriate, and a company needs to recognize which kind of R&D activity is undertaken, e.g. project investment vs. option investment (Faulkner 1996) to derive the corresponding management strategy.

In order to discover and finally select long-term projects with growth potential, Smit/Trigeorgis (2006) propose a real option growth matrix. The matrix supports the selection of a R&D project mix in line with corporate strategy. An expanded NPV is calculated by summing the base NPV of existing projects and the present value of the growth opportunities, accounting for volatility and degree of flexibility. Projects are then displayed in one of six regions in the matrix: invest now, profitable projects but with low potential, profitable projects with growth potential, opportunities with commercialization potential, opportunities with low profitability and low growth potential or invest never. The matrix shows where current projects and opportunities are strategically located and when it is advisable to invest, i.e. choose to start the project. In order to capture the specific capabilities of the company and as assigning monetary values and calculating an expanded NPV is often not possible for completely new R&D project investments, McGrath/MacMillan (2000) propose a qualitative method called "STAR" (strategic technology assessment review) in order to detect promising options. The STAR technique uses a questionnaire where scores are assigned to lists of statements covering demand, market and adoption assessments, blocking factors, competitive moves, size and sustainability of revenues, development and commercialization costs, involved uncertainty, leverage potential, dependence on standards, and industry novelty. Reviewing the scores in each category allows assessing the project's potential along the stated dimensions as well as defining alternative ideas and future actions. A similar qualitative method can be used by scoring and classifying projects in a portfolio into three categories (low-medium-high) for both market and technology uncertainty (MacMillan/McGrath 2002). According to the respective position along the two dimensions the portfolio is divided into five categories (see Figure 3). Stepping-stone options are highly uncertain in both dimensions and only a small initial investment should be made. Frequent reviews and sequential decision-making increase the potential of these growth options. For positioning options the technical uncertainty is very high but the market is defined, whereas for scouting options the reverse applies. Mapping these option types as well as enhancement and platform launches with lower uncertainty generates a strategic portfolio, and the organization can further decide where to focus, commit resources or add new projects.

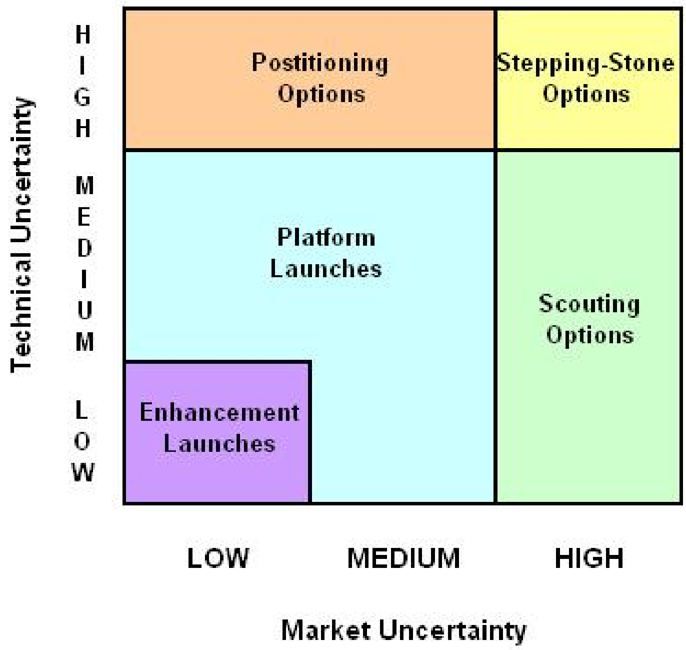

Figure 3: R&D Project Types according to technical and market uncertainty; Source: MacMillan/McGrath (2002)

The mapping techniques (MacMillan/McGrath 2002, Smit/Trigeorgis 2006) provide the holistic view needed by organizations to discover which projects provide immediate returns, and to decide for which projects it is worth to commit resources and an initial investment to ensure future growth for the organization.

An overview of the evaluated project and portfolio selection methods and key article classification is provided in Table 1.

The evaluation of a project portfolio does obviously not end when the final projects are selected and companies need to exercise as well a "will to kill" if necessary (Cooper/Edgett 2003) and conduct reviews in order to react to changing conditions to ensure success (McDonough/Spital 2003). The continuous assessment of projects as well as operational decisions to mitigate risks or flexibly react to evolving options during the project management process itself will be studied and presented in the following chapter in detail.

Table 1: Project Selection and Portfolio Planning: Methods and Classification of Key Articles

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Q-Sort model	Qualitative	Project Selection; Evaluation of all prospective projects among a list of chosen criteria	Priority list of potential projects; Subjective judgment; Global project view	Project risk can be evaluated subjectively	Pure ranking; Highly subjective method; No interdependencies or criteria weights considered.
Pairwise Comparison	Qualitative	Project selection; Project pairs are compared among defined criteria and ranked afterwards. Method more suitable for a smaller number of projects	Ranked list of potential projects after all pairs of projects have been assessed; Global project view	Comparisons can include subjective risk consideration (i.e. "which project is riskier?")	Neglects interdependencies and criteria weights; Method only allows for overall project view
Scoring Techniques: A) Unweighted 0-1 factor model B) Unweighted factor scoring model C) Weighted factor scoring model	Qualitative and Quantitative	Project selection; Scoring of projects according a list of chosen factors; Counting how many are met (A), by how much they are met on a scale (B) or additionally assigning weights to single criteria (C).	Ranked list of prospective projects according overall score (for C: formula with individual factor weights).	Level of risk can be one of the scoring factors. (Fix) costs if project fails can be considered in the formula.	Limited on amount of included factors; For C, weights allow for differentiating among criteria importance.
Analytic Hierarchy Procedure (AHP)	Qualitative and Quantitative	Project selection; Hierarchy (tree structure) of weighted criteria is created; Projects are evaluated in matrices using pairwise comparisons.	Ranked list of potential projects after calculation of overall value considering all levels of criteria.	Level of risk can be among the weighted criteria.	Hierarchy allows for inclusion of many factors. Hierarchy structure can be modified for individual selection processes.

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Payback Period	Quantitative	Project selection; Investment divided by the expected yearly cash return; for selection shorter time period is preferred	Time period until original investment is covered	No	No consideration of time value of money and cash flows after investment is covered
Net Present Value (NPV)	Quantitative	Project selection; Comparison of discounted cash streams with the initial investment. Sum of discounted future cash flows should be larger than investment	Present value of planned project investment. Comparison of different projects' NPVs for selection decision	With discount rate; Choosing project(s) which yield a high NPV	Simple to use; Same discount rate for all periods not realistic; Biased towards the short-run; No consideration of "softer" project characteristics; Difficult to predict cash flows
Internal Rate of Return (IRR)	Quantitative	Project selection; Evaluates required rate of return to equal present values of cash out- and inflows	Return rate required to consider investing in the project	Comparison of generated IRR with other investment opportunities	Not suitable for comparison of projects with very different characteristics.
Profitability Index (present value index or benefit-cost-ratio)	Quantitative	Project selection; NPV of future expected cash flows divided by the investment costs	Index value; if larger than 1 project is selected	Within NPV discount rate	see NPV above
Decision Tree Analysis (DTA)	Quantitative	Project selection; Graphic representation of alternatives/stages with nodes in a decision tree. Assignment of probabilities and calculation of max. NPV	1) Chart (tree) with all possible stages 2) Tree branch with highest NPV	Within NPV discount rate	Alternatives graphically displayed; complex when many nodes; Same limitations as NPV above

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Composite Model (Coldrick et al. 2002)	Qualitative and Quantitative	Hybrid approach using three selection methods: 1) weighted scoring model 2) cost-benefit calculation 3) DCF (NPV) assessment	Simple ranking for basic research, cost-benefit and DCF calculation for (applied) research and development	Risk evaluated only as cost-benefit ratio ("risk level")	Isolated project view. No portfolio generation but applicable for comparison of similar projects
Portfolio Management (Cooper et al. 1998)	Survey	Characteristics and success of portfolio techniques studied	Hybrid method needed to reach overall satisfactory results. Importance of portfolio balance and overall strategy highlighted		List of advantages and disadvantages of financial techniques, scoring methods and graphic displays
Mathematical Programming and Decision Support (Ghasemzadeh et al. 1999)	Qualitative and Quantitative	0-1 integer linear programming method to derive NPV and select a project portfolio. Possibility to combine with a DSS ("interactive adjustment")	Evaluates optimal start points. Accounts for resource constraints and varying resource consumption, interdependencies and overall risk	Constraint for risk balance can be included in the program (max. percentage of projects with a certain risk level in the portfolio). Risk can also be assessed when balancing the portfolio output	Sensitivity analysis after calculation of optimum might be required due to uncertain input variables

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Portfolio Creation Model (Graves et al. 2000)	Quantitative	Portfolio selection by linear programming – minimizing overall risk for a defined overall return	Efficient frontier displaying risk and expected return for respective portfolio; Graphical support for later decision	Risk adjustment with probability distribution of project success (spread of return)	Simple to run model, few inputs necessary. Interdependencies neglected
Data Envelopment Analysis (DEA) and Value Creation Model (VCM) (Linton et al. 2002)	Qualitative and Quantitative	Project selection by usage of DEA to pre-sort possible projects and later apply in-depth analysis with VCM	Method creates ranking of projects with DEA (financial and categorizing variables) and further graphic evaluation (e.g. for interdependencies) with VCM	Risk adjustment within NPV calculation for DEA ranks	Two-step model considering both objective and subjective criteria; more holistic view on portfolio and detailed investigation of specific project groups
Real Options Approach (McGrath/ MacMillan 2000)	Qualitative	Questionnaire to evaluate and score potential projects, applying real options thinking: strategic technology assessment review (STAR)	Investments and cash flows considered in survey questions; scores in output as discussion base for decision	Covered within individual questionnaire categories	Group discussion of assessed categories enables quite fast decision making
Strategic Options (Mitchell/Hamilton 2007)	Qualitative (Strategic)	Article highlights the distinction of R&D as knowledge building, strategic positioning or business investment - each requiring a specific investment evaluation strategy	Knowledge building, e.g. basic research: treat as "cost of business"; Strategic positioning: options approach; Business investment: NPV, DCF, ROI methods	For strategy evaluation within option approach, for investment decision with financial means of ROI	Base to evaluate projects (and risks) correctly is to first of all define the correct strategic goal and to apply the appropriate financial method

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Priorization Model (Ringuest et al. 1999)	Quantitative	Portfolio mix evaluation. Calculation of risk-adjusted return and study effects of adding single projects to overall portfolio	Priorization according expected portfolio return considering overall risk	Risk mitigation within portfolio considered by calculating risk-adjusted return	Simple model, but considers only which project to add to an existing portfolio; No portfolio generation/balance
Mathematical Programming (Sefair/Medaglia 2005)	Quantitative	Portfolio generation using mixed-integer programming to derive projects to select and their optimal sequence	Optimal resource allocation and starting points for projects within a portfolio with max. overall NPV and min. NPV variability	Risk incorporated as the volatility of the NPV	No interrelations between projects considered
Real Options Approach (Smit/Trigeorgis 2006)	Quantitative	Portfolio of options represented in a Real-Option-Growth matrix: two dimensional space with 6 regions according NPV and PVGO (present value of growth opportunity)	Graphic representation of the portfolio; Allows to evaluate strategically and flexibly; Possibility to include competitive actions	Considers (future) uncertainty by flexible decision making	Involves as well qualitative evaluation of the portfolio. Requires a management capable to flexible strategy adjustments
Mathematical Programming (Zuluaga et al. 2007)	Quantitative	Mathematical linear programming model to evaluate the selection and timing of interdependent projects. Assessment of the portfolio's NPV	Optimal portfolio scheduling of projects within the available budget	Portfolio risk minimization not included	Interdependencies only for pairs of projects included

4. Project Management Process

Although project management (PM) is studied since more than 50 years, the involved processes are still continuously modified and expanded. The discipline remains dynamic as more and more different situations and applications evolve where projects are the prevailing business construct (Gardiner 2005) but also as different projects need different management styles (Shenhar 2001). Further, there are differences in PM maturity between different industries, i.e. the extent as to PM processes perform (Cooke-Davies/Arzymanow 2003). While early PM research focused on pure planning, scheduling and cost control, later the human factor and team behavior were studied (Kloppenburg/Opfer 2002) and more recently a turn to the strategic aspects took place (Shenhar/Dvir 2007). Based on this evolution, Shenhar/Dvir (2007) derive three central views of PM corresponding to these research steps: operational/process, team/leadership and strategic/business. The overall goal remains to achieve the "holistic view" by merging these distinct areas.

The successive project phases can broadly be classified into initiation and definition, planning and development, execution and control, and closure (Gardiner 2005) or selection, execution and implementation (Pillai et al. 2002). It is possible to itemize the broad phases into more specific stages which might make it possible to discover and address risks in the project faster and more effectively (Ward/Chapman 1995). Project phases depend on the type of R&D undertaken, as for example pharmaceutical R&D early phases are screening and validation, followed by pre-clinical development and clinical tests and finally registration (Hartmann/Hassan 2006, see Figure 4).

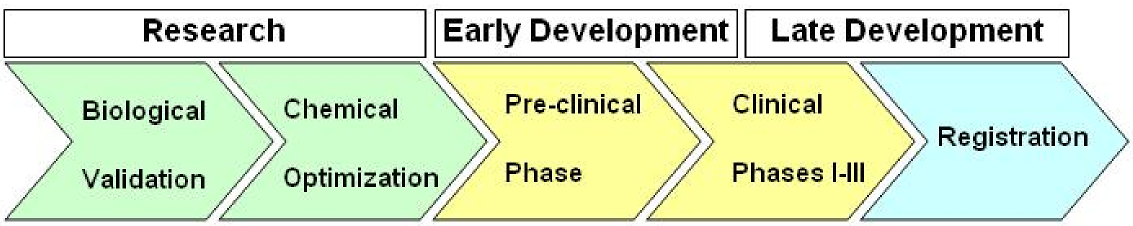

Figure 4: R&D process in pharmaceutical industry (source: Hartmann/Hassan 2006)

There is the inevitable need to manage constantly and comprehensively each phase as the result or product of a project develops over time, involves interactions with parties internal and external to the firm, and is exposed to fast changing conditions.

The subsequent phases from the starting point to completion yield to the PLC individual projects passing through. The fast changing environmental conditions yield shorter life cycles as firms need to speed up new product developments and introductions (Shenhar/Dvir 2007). Therefore, PM for new product development projects should be adapted to these dynamic conditions (Pons 2008). A promising approach which is commonly applied for managing R&D projects over their whole life-cycle is the implementation of a *stage-gate-process* (Cooper et al. 2000). The stage-gate-process comprises the need for continuous evaluation of risky projects, a thorough portfolio management in line with the corporate strategy and assessment of effective resource allocation. For new product development a process consisting of five stages and five gates was developed (see Figure 5). The stages represent development steps or activities which result in a certain outcome at the end of each stage. In general, the stages consist of preliminary and detailed investigation, the product development as well as test and validation, and product launch. The gates are in-between the individual stages and at gate meetings the performance criteria are reviewed and decisions are taken of whether to continue or to stop, that is making "go/kill decisions". Ward/Chapman (1995) suggest also including a "maybe" decision, as some projects might need more thorough evaluation. At the gate review meetings, besides the general project status, pre-defined project hurdles are checked, while these need not to be constant across the whole process. Changes in parameters, especially investment and risk level, require adjustments of hurdle criteria from stage to stage (Walwyn et al. 2002).

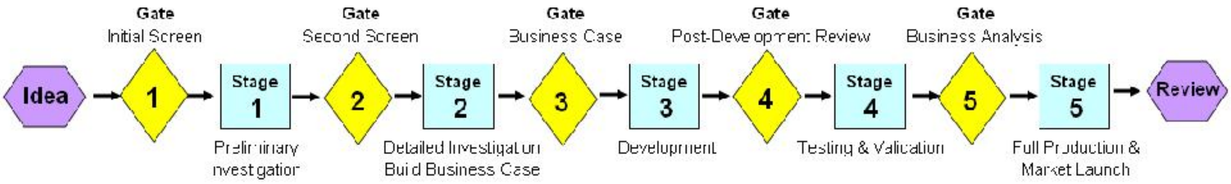

Figure 5: Stage-gate process for R&D projects (source: Cooper et al. 2000)

Cooper (2006) proposes an additional stage-gate-process for technology development projects which involves three stages and four gates and then passes on to the 5-stage/5-gate development process (see Figure 6).

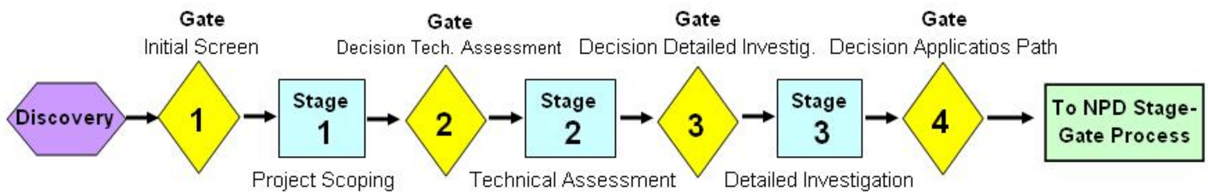

Figure 6: Stage-gate process for technology development (source: Cooper 2006)

5. Risk Management in Project Execution

5.1 Relation of Risk Management to Project Management

The interlinkage between risk management (RM) and PM in general can show different shapes. Firstly, the view of RM which was traditionally followed regarded it as just being one part in the overall PM process (Grey 1995, Chapman 1997). The second concept considers RM as the overwhelming purpose of PM. Therefore, due to the fact that no project carries zero risk, risk is the reason making PM actually necessary. Another perspective is that RM accompanies the whole PM process and is considered in all phases (Grey 1995). This last view is probably the one which is mostly applied and where the management of risks is seen as one of the most important tasks in the overall PM process (Raz/Michael 2001). RM can generally be considered as the "creation of previously unknown information" (Perminova et al. 2008) and integration of the obtained knowledge at the corporate level, reusing it for new projects in future (Ward 1999a). A reasonable balance between the costs for risk reduction and its benefits or additional value should be reached, i.e. only when expected utility of risk reduction can further be increased, additional spending for RM is reasonable (De Klerk 2001). The overall process should help finding risk efficient options for the firm which can be achieved by displaying the Pareto optimally solutions along a risk efficient boundary, conceptualizing the risk-reward trade-offs of the project completion alternatives (Chapman/Ward 2004). Still, it is important to realize that RM cannot remove all the risk but provide means to manage them strategically (Holt 2004). However, these methods might change from one firm to the next and a customized process needs to be created. Finding the most suitable process involves also knowing about the individual firms' risk tolerance, i.e. how many high risk projects to include (De Klerk 2001). For a cost-effective and efficient risk management process (RMP) the wider context of the project and the basic attitude, knowledge and motivation of the involved people are also important to consider (Ward 1999a). While empowering project teams is motivating and often needed for fast decision making, it creates as well a trade-off with the holistic view over the complete project or portfolio. A solution can be allowing certain decision making at the operational level, but evaluating the overall project or portfolio landscape at pre-defined reviews with senior management (Williams 1997), e.g. at gate review meetings.

5.2 Risk Management Process

The management of risks is accompanying the whole stage-gate or general project development process. The basic phases of a RMP contain identifying, assessing and analyzing risks qualitatively and quantitatively in order to plan response strategies which need to be monitored and tracked as well as controlled and reported. The nomenclature of the process phases varies among different authors, while basically always the above mentioned tasks are included (Raz/Michael 2001, Ben-David/Raz 2001). It is important to consider that all steps of the RMP are highly iterative and cannot be seen as isolated phases (Chapman/Ward 2000). Further, the process needs to manage both the threat as well as opportunity outcomes of risk (Hillson 2002) as only the combined management of opportunities and negative risks can ensure the holistic project view (Olsson 2007). In order to address all types of risks correctly during the process, the underlying nature of the problem needs to be recognized. Holt (2004) distinguishes between tame problems, messes, wicked problems and wicked messes, which combine messes and wicked problems. Solutions for tame problems can be found analytically as they can be approached by rational thinking. Messes are structurally complex constructs and require the thorough examination of interdependencies. Resolution of messes requires highly iterative RM processes. If high behavioral complexity is present, wicked problems occur. The main difficulty of wicked problems is that the parties involved possess strongly diverging attitudes and beliefs which lead to no unique solution. RM needs to find solutions to avoid confusion and try to merge the alternative views. Additionally, when the project conditions change or new risks emerge, the RMP must be flexible to react quickly and provide new solutions (Jaafari 2001). There might be the need for organizations to customize the RMP with a focus on their individual needs (Chapman 2006). A risk register is a supporting tool for the ongoing documentation and continuous reassessment of the various risks (Leonard 1995). Again, it can be customized to the specific requirements of a company but generally should contain a depiction of the risk characteristics, its impact and probability, the appointed risk owner, and one or more mitigation strategies. As it is mostly software-based, various outputs can be generated like graphs, progress and status reports as well as analyses of the overall project risk (Patterson/Neailey 2002). Though difficult to reach for very complex constructs, emphasis should be put on showing as well interdependencies between individual risks and not treating risks in isolation (Ward 1999b).

5.2.1 Risk Management Planning and Identification

Before identifying risks it is important to ensure that all involved people agree on and understand the project objectives, that responsibilities are assigned, and that there is clarity about the employed methodology (Hillson 2002). The subsequent risk identification needs to consider the various risk sources and should be conducted early in the project as "the real risks in any project are the ones that you fail to identify" (Ward 1999b). The phase aims at generating an extensive description and definition of possible risks in a risk list (Kasap/Kaymak 2007). Not only awareness about which risks are present is needed, but also how the individual risks evolve over the PLC, i.e. which risks are resolved in early phases, which exist continually and which evolve late (Miller/Lessard 2001). During the identification phase risks are distinguished from problems. While problems are instantly managed, risks are further assessed (Wu et al. 2006). Techniques used to gather inputs about possible risks involve group and individual techniques, like brainstorming, workshops, checklists, interviews, diagramming (influence diagrams) and creativity techniques as well as data from already completed projects, lessons learned and an examination of the work breakdown schedule (WBS) which covers the single work packages of the project. These methods can be classified into experience-based and knowledge-based (Royer 2000). In order to cover different aspects, combining different techniques might yield better results (Hillson 2002). SWOT analysis and force field analysis are useful techniques to explicitly address and include the positive effects of risks (Wu et al. 2006).

5.2.2 Risk Assessment and Analysis Methods

A large variety of methods and tools exist to assess and analyze the identified risks which can occur within the life of a project (see overview in Table 2). Risk assessment can be quite resource intensive and complex, and inputs may be insufficiently available (Zhang et al. 2008). These can be some reasons why a cross-industry study conducted by White/Fortune (2002) revealed that 65% of the surveyed did not use any specific risk assessment tool at all, while standard PM software or cost-benefit-analysis were used by almost all who participated in the survey. Techniques for risk analysis can be qualitative in nature or quantitative, while a mixture of both might yield comprehensive results. Mainly, the aim is to prioritize potential risks, estimate the effect on the overall project to finally derive an appropriate response or mitigation strategy. Qualitative techniques include cause-and-effect diagrams and failure mode and effect analysis (FMEA) which lists causes, consequences and possible resolution activities of identified failure modes, i.e. risks. Further, a qualitative classification of risks in a matrix, consisting of "high-medium-low" chance of risk occurring and "high-medium-low" impact or consequence, can yield an initial understanding and first prioritization for further actions (Harrison/Lock 2004). Especially when not much information is available, qualitative assessment is quite effective (Ward 1999a).

Quantitative tools include critical path analysis (CPA) or project evaluation and review technique (PERT) to assess schedule variation risk (Pillai/Rao 1996). These methods however have been criticized for not considering the randomness of the time variable but instead using averages (Elmaghraby 2005). An alternative to these probabilistic methods is to assess uncertainty of schedules using fuzzy logic methods (Liberatore 2008) Fuzzy critical chain methods can also incorporate schedule changes and resource constraints and do not require historic data which might not be existing for certain R&D projects (Long/Ohsato 2008). Another possibility is to assess risks using decision trees which can depict the various consequences of different risk events by assigning probabilities to tree branches. Calculation of the expected NPV for all alternatives enables the decision maker to select the utility maximizing alternative. Nevertheless, decision theory approaches hardly capture the overall picture of the whole R&D project, as quite often the life-span of the project is too long to include all eventualities (Miller/Lessard 2001).

Extensions of the pure quantitative matrix with "high-medium-low" classifications of risks are probability-impact-matrices (PIM). Here, risk exposure is calculated by multiplying the assigned probability of a risk with its forecasted impact resulting in a probability index. This applies of course also to opportunities which should be considered and evaluated (Hillson 2002). Due to the inherent uncertainty about parameters and the subjective generation of probabilities (Chapman 2006), variability of values can be incorporated for PIM calculations. Instead of resulting in one definite risk index value, then a range is assessed (Chapman/Ward 2000). This approach might reflect the range of possibilities more appropriately and realistically. Another model building on variations of parameters is sensitivity analysis. The method calculates the impacts on an outcome (e.g. NPV) by varying the input variable (e.g. cash in-flow) along a range of different forecasted values (Harrison/Lock 2004). A simulation technique for risk assessment which is evaluating the likelihood of combinations of random values occurring is called Monte Carlo. It operates by iterating all possible values of an uncertain parameter resulting in a histogram showing the range and probabilities of occurrence (Grey 1995).

The assessment and analysis models based on probability theory have limitations and are criticized as not correctly or completely modeling reality in projects (Pender 2001). Though the described methods might be sufficient for risk assessment for some, e.g. lower risk R&D projects, others might require more dynamic techniques which emphasize the combined effect of strategic and economic considerations of R&D project management (Mitchell/Hamilton 2007). This lead to the application of real option theories for R&D projects which is described later in this chapter as a method for analysis and as a special case of risk response. An overview and comparison of various methods and models is provided in Table 2 at the end of paragraph 5.2.4.3.

5.2.3 Risk Mitigation and Response Planning

After assessment and analysis of project risks, appropriate means and tactics need to be derived in order to cope with the situation. Risk responses should be "appropriate, achievable and affordable" (Hillson 2002). These characteristics again highlight the risk efficiency idea as well as the cost-benefit trade-off of response strategies. It is necessary to achieve a balance between the required costs for a response strategy and its expected effect on risk exposure. However, there might exist interdependencies between different strategies and new risks might be caused or enhanced by the implemented strategy. In order to cope with the latter effect of secondary risks, Ben-David/Raz (2001) proposed a model which minimizes the total risk costs, i.e. sum of the expected costs when the risks occur and the costs for the risk response actions. As project managers "tend to manage risk by denial, sidestepping, and attempting to shield themselves" (Royer 2000) decisions on the best mitigation action for important risks should be taken by a committee encompassing different views.

Generally, there are *specific* responses which apply to a single identified risk and *general* responses which affect several risks (Chapman/Ward 1997). The following risk response strategies can be distinguished: modify objectives, avoid, accept, mitigate, or transfer/share the risk, abandon the project, or create a contingency plan (Turner 2005, Gardiner 2005). Some uncertainty can be decreased by concretely defining the product or modifying initially set objectives. Avoidance is obviously not possible for all kinds of risk and in all situations, but if an alternative solution is equally feasible, the risk could be avoided by altering the way the project is undertaken. The acceptance of risk can concern either small, rather unimportant risks which if they occur do not have a large effect or risks where avoidance is not possible. Accepted risks will be monitored carefully, and if necessary a different action taken. Decisions about acceptance and avoidance are driven to a large extent by the organizations' risk tolerance, as a firm with a high risk tolerance might accept risks which might be treated differently if low risk tolerance is present (Turner 2005). Piney (2003) also highlights the fact that expected utility and risk tolerance have an impact on the decision making and choice of risk responses. Risk mitigation involves actions which reduce the probability of occurrence or the intensity of impact. Mitigation requires that the risk source is completely understood in order that effective means can be found which have a consequence on probability or impact. For certain risks other parties might be able to better manage them. Hence, a risk transfer or sharing should take place, e.g. by insuring or contracting (Turner 2005). In situations where a continuation of the project is not possible, maybe due to the outcome of a pilot study test or a risk which cannot be borne at all, the only strategy is to abandon the project. For very critical tasks in the project, contingency plans should be created (Gardiner 2005). As in spite of planning and forecasting different eventualities still something unpredicted can happen, the firm should think about alternative solutions if none of the above mentioned response strategies might be feasible or possible. The contingency plan finally is pursued if a certain trigger event has happened.

Depending on the extent of control (controllable vs. uncontrollable) and the type of risk (systemic vs. specific) different management strategies should be applied and options created to decide on the response strategy. While for specific, controllable risk traditional mitigation is suitable, uncontrollable but identified risks should be transferred or hedged. Broad, controllable risks should be diversified via portfolios, whereas for systematic, uncontrollable risks transformation or influence on the controlling institutions should be reached (Miller/Lessard 2001).

As the common risk treatment strategies handle mainly negative uncertainty, Hillson (2002) proposed strategies responding to opportunities, namely exploitation, sharing, enhancement and ignorance. Exploitation is the counterpart of avoidance and concerns making sure that the event will definitely occur. Another strategy is to share the potential opportunity with another party who can best make use of it. Moreover, enhancement of the opportunity can be conducted by increasing probability or impact of occurrence. Finally, an opportunity can also be ignored by not actively taking any action.

An additional risk response mentioned by Chapman/Ward (1997) is to "keep options open" which essentially means to delay commitment. Real options analysis, flexible reaction to risks and exploitation of opportunities will therefore be examined in more detail in the following paragraph.

5.2.4 Real Options Thinking

5.2.4.1 R&D Projects as Strategic Options

Though probabilistic methods (e.g. Monte Carlo) and simple DCF methods are widely used and implemented for project evaluation and risk analysis, many researchers criticize the application of these techniques for R&D projects in certain conditions and propose a completely different approach to cope with uncertainty (Faulkner 1996, Newton et al. 2004, Herath/Bremser 2005). Especially when facing the highly uncertain environment of basic research or long-term research activities the urge for flexibility in decision making and to react quickly when conditions change or new information becomes available is apparent (Mitchell/Hamilton 2007). Therefore, the approach of real options thinking is a different way for assessment and response to R&D project uncertainties, building specifically on the successive decision making process (Schwartz/Zozaya-Gorostiza 2003) and applicable in combination with stage-gate-processes (Boer 2003). The technique incorporates the economic value as well as the strategic value of R&D activities (Smit/Trigeorgis 2006). Hence, it goes beyond DCF techniques as it considers additional information in different phases of the development process and enhances the exploitation of opportunities in R&D projects (Faulkner 1996), as well as the managerial flexibility to react to market uncertainty (Trigeorgis 1996, Pennings/Lint 1997). Nevertheless, real option models which consider the specific characteristics of a certain situation might be required, i.e. methods adaptable to the individual firm's environment (Willigers/Hansen 2008).

As general models are not appropriate for all conditions or make strict assumptions there are limits in the use of real option approaches in day-to-day decision making in project environments (Bowman/Moskowitz 2001). Moreover, project managers act intuitively when delaying decisions until some uncertainty is resolved and would not apply a calculatory mechanism or think explicitly in "real option frameworks" (Huchzermeier/Loch 2001). Although the pharmaceutical R&D environments are frequently used for theoretic evaluations about real options, and case studies where firms used real option thinking exist (e.g. for Merck, Bowman/Moskowitz 2001), generally the analysis techniques are not widely applied in practice (Baecker/Hommel 2004, Hartmann/Hassan 2006). Hartmann/Hassan (2006) therefore distinguish between real options reasoning, i.e. flexible decisions are made without calculatory justifications, and real options pricing, i.e. application of valuation techniques.

5.2.4.2 Real Option Types in R&D Projects

The different types of real options comprise options to defer, stage, abandon, expand, contract, shutdown/restart, switch input or output and explore (Trigeorgis 1996, Benaroch 2001). The option to defer allows delaying commitment until more information becomes available. A stage option exists when single investments evolve at single development steps and the overall activity can be completely stopped and may be continued at a later time, while an abandonment option stops the activity permanently. Altering operating scale involves the options to expand, contract and stop/restart production. Depending on the external conditions firms decide whether to commit additional resources, reduce them or stop temporarily and restart later. Switching inputs is the option to produce still the same good but with different inputs, i.e. process flexibility. Product flexibility is the option to switch the outputs, i.e. the produced goods. The explore option involves gaining more information for example with prototyping or pilot studies. Huchzermeier/Loch (2001) add the option type of "improvement" for R&D projects, which represent changes in activities during the project aimed at performance improvement.

The various option types can be classified into three groups (Baecker/Hommel 2004): learning, insurance and growth options. Learning options comprise waiting, staging and switching options and allow reacting after more information is available. The group of insurance options contains abandonment, shutdown and switch, and help to cope with negative external risk. Thirdly, growth options like expansion or exploration enhance future business opportunities. This option type was already considered in the project selection section above.

In projects normally more than one of the stated option types are present and interact, and the first decision to select a project and commit an initial investment creates a series of further options during execution (MacMillan/McGrath 2002). These compound options can be intra-project compound options, when the options are interrelated within one project or inter-project compound options, when they concern different projects. Further, they can enhance a certain risk while at the same time decrease another. The value of compound options can be additive (equal to sum of the individual option values), substitutive (smaller than sum of single options) or synergetic (larger than sum of single options). In order to assess the optimal investment strategy possible interactions and their effects on the real option cost need to be evaluated as otherwise the further investment alternatives are over- or under-estimated (Benaroch 2001).

Real options in R&D projects are mainly considered as American options (Mitchell/Hamilton 2007, Luo et al. 2008, Schwartz/Zozaya-Gorostiza 2003). They are not bound to a certain expiration date but instead can be realized before. The investment itself is considered as buying an asset which resembles the financial call option, and in the case of an R&D project enables successive decisions about whether to proceed to the next process step (Faulkner 1996). Options during the course of the project can also be put options, e.g. exit or abandon the project, decreasing the potential downside risk of the project or avoiding loss (Miller/Waller 2003). In general, both put and call option types control risk by altering the probability distribution of the investment value (Benaroch 2001). Though Pennings/Lint (1997) considered R&D options as European, i.e. they can only be exercised at their expiration date, this view might be only related to the overall R&D activity and with respect to a certain launch date and not to the various options which are present during the development where management mostly has a certain time-frame available for final decision-making (Schwartz/Zozaya-Gorostiza 2003). Overall, there is no general statement to be derived of whether options in a R&D project are American or European, as this depends on the respective real situation (Newton et al. 2004).

5.2.4.3 Identification and Evaluation of Options

Nevertheless, the first step is again to identify potential risk sources and uncertainties, both opportunities and threats. The firm identifies risks the project might be exposed to, and subsequently possible option strategies are derived and the relations between single options as well as whether new risks arise due to exercising an option evaluated (Benaroch 2001). Before calculating the NPV including option values, decision trees are frequently used in order to assess the structure of possible alternative scenario (Faulkner 1996). The identification of real options can be done by expert teams who forecast the respective consequences, and should also involve a sensitivity analysis. A tool to help in identifying certain risks and the corresponding possible option strategy is an uncertainty-option matrix. (Bräutigam et al. 2003). Miller/Waller (2003) propose a method called "integrated risk management process" which does not require to calculate the option value after identification, but instead qualitatively evaluates real options in combination with scenario planning. The process starts with scenario planning to detect plausible future states of the project, corresponding uncertainties and strategic actions which are finally combined to reveal the overall exposure to the main uncertainties. In the second step, using real options reasoning, various investment possibilities are evaluated to alter risk exposure, e.g. deciding whether to invest in additional business.

In identifying risks, the main distinction needs to be made between market (or exogenous) risk and unique (or technical, endogenous) risks (MacMillan/McGrath 2002). While unique risk can be hedged in portfolios and therefore controlled to a certain extent, market risks cannot be hedged and the firm is exposed to uncontrollable volatility due to external influences (Luo et al. 2008, Boer 2002). If R&D managers face market uncertainty they can either decide to wait and invest at a later point in time, or they might invest a small amount and create a growth option depending on how the market develops (Oriani/Sobrero 2008). Alternatively, technical uncertainty can create an option to wait until the technology is proven, or the firm invests in alternative technologies with the ability to switch later (McGrath/MacMillan 2000). Oriani/Sobrero (2008) show that for very uncertain markets with high growth levels an initial investment and creating a growth option is valuable for the firm. Additionally, if a certain level of technology uncertainty is reached, the value of the switching option decreases, i.e. it would be better to wait instead of hedging different solutions.

The flexibility of management behavior to react at various stages within the project execution to new situations creates an asymmetric probability distribution of the project's NPV as compared to the case when management cannot react actively. For quantitative evaluation of an R&D project with a real option approach different mathematical algorithms exist (Trigeorgis 1996). These yield an expanded or strategic NPV by adding to the standard or passive NPV of expected cash flows an option premium which represents the value of flexibility, e.g. by deferring continuation of the project. The inputs required for real option evaluation are the future investment cost which resembles the exercise price of a financial option, the present value of expected cash flows representing the value of the stock, a risk-free interest rate, the time until the option or opportunity expires, and the project value uncertainty which should indicate the stock volatility. Real option analysis converts all underlying stochastic processes into a risk neutral state of the world (Willigers/Hansen 2008). A model which was often proposed and used in the literature is the Black-Scholes formula (Newton et al. 2004, Trigeorgis 1996). However, the method is problematic for R&D projects as it is designed for European type options and cannot represent compound options (Willigers/Hansen 2008). Another inappropriate assumption of the method is the log normal distribution of the future uncertainty which is not realistic for R&D projects (Faulkner 1996, Luo et al. 2008). Consequently, it is difficult to assess the volatility of the underlying asset which is required for calculating the option value as no similar or comparable traded stock or historic data might be available for the specific R&D activity being evaluated (Bowman/Moskowitz 2001). A method to avoid this problem is to assume that there is no traded asset and instead use the present value without flexibility of the project as the underlying asset (Schneider et al. 2008). Pennings/Lint (1997) include in their model a poisson jump process where amount and sizes of jumps of business shifts indicate the variance of the underlying asset. A model which is not dependant on the log normal distribution is the binomial lattice method which can be seen as an extension of decision tree analysis with adjustment for risk-neutral probabilities and allowing for discounting with a risk-free interest rate (Faulkner 1996, Trigeorgis 1996). The binomial tree has the advantage that it, besides providing the option value, visualizes the alternative decision possibilities and therefore might be more easily understood and implemented by practitioners (Bäcker/Hommel 2004). Therefore, binomial trees are often used for case studies on real option applications in practice (Schneider et al. 2008, Santiago/Bifano 2005). An extension of the binomial lattice method considering explicitly interdependencies between options is the lognormal transformed binomial approach (Benaroch 2001). The lognormal transformed binomial approach is particularly suitable to model the complexity of many interacting real options. Further, it is an efficient and stable technique which can incorporate market moves or jumps, e.g. due to competitive actions (Trigeorgis 1996). Binomial trees can be created for private and market uncertainties and finally combined into an integrated multi-dimensional tree showing the various possibilities within the project (Schneider et al. 2008).

Models for real option assessment in R&D projects have been modified or extended into various dimensions to account for specific conditions and derive optimal strategies, like under which conditions it is optimal to wait before investing, accounting for high volatility in cost and benefit streams of development projects (Schwartz/Zozaya-Gorostiza 2003). Further, comparisons have been made between traditional NPV and real option evaluations to show how decisions for project abandonment vary due to different project characteristics and underlying model approaches for pharmaceutical R&D projects (Willigers/Hansen 2008). The results show clearly that especially when large investments are required, managerial flexibility is valued very high, as the project can be abandoned and therefore downside loss avoided. However, if technical risk is resolved early in the project, calculatory results of expected NPV and real option methods are quite similar.

The real option notion that the value of flexible reactions to uncertain situations is higher if there is more variability is theoretically proved. Huchzermeier/Loch (2001) however state that this depends on when uncertainty is resolved, and whether decisions have already been made. Additional to payoff uncertainty, the authors included operational uncertainty, i.e. uncertainty about budget, performance, market requirements and schedule, and created a set of options which can be continued, abandoned or improved in each period. They show that the real option theory holds for market payoff and budget variability, but that for performance and market requirement uncertainty more variability can decrease the value of higher flexibility and reduce the real option value. This effect applies if decisions are made and then operational uncertainty is resolved, more information becomes available or costs and revenues arise.

As real option models mainly deal with the value of strategic flexibility within the firm, strategy considerations which go beyond the company and concern competitive moves are more recently included. Competitive moves create trade-offs between different option types, like the deferral and growth option, and strategies to derive about entry, continuation or exit (Bäcker/Hommel 2004). Especially in industries with high R&D intensity, first mover advantages will turn an expansion option more valuable than deferral (Driver et al. 2008). The concept of strategic commitment and competitive behavior represented by game theoretic approaches is therefore linked to real options theory. Game theory and the consideration of competitive moves can then indicate when specific options should be kept, when it is optimal to behave flexible or when it is best to invest as a leader or follower (Smit/Trigeorgis 2006). The inclusion of competitive movements has effects on the optimal option timing, i.e. might diminish the value of the option to wait and also influences expected payoffs. Further, game theory real option approaches where uncertainty is reduced over time, e.g. with signals, help to detect when new technology arrivals can lead to second mover advantages (Huisman et al. 2004). In order to being prepared and able to react to possible technology shifts, firms might follow flexible design strategies to remain competitive and exploit market situations optimally.

Table 2: Risk Assessment and Analysis: Methods and Classification of Key Articles

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Failure Mode and Effect Analysis (FMEA)	Qualitative	Listing of project situations / potential causes, consequences and resolution activities	Overview of potential project states, effects and possible mitigation actions	Within description of failure modes and derived actions	Thorough consideration of various possibilities, but might contain subjective judgments
Risk Matrix	Qualitative	Two dimensional ranking of chance of risk & corresponding impact in "high-medium-low" cluster	Matrix displaying possible risks and consequences	Within classification matrix	Could be initial project evaluation, still subjective classification
Decision Theory Approaches	Quantitative	Creation of a decision tree displaying possible outcomes with respective probabilities in tree branches; calculating NPV for all routes in the tree	Graphically displayed possibilities; Expected NPVs for the various alternatives	Within branches of decision tree and assigned probabilities	Might not depict complete picture as structure would become too complex for large projects. Decision tree could be baseline for other risk evaluation methods, e.g. for real option approaches
Probability-Impact-Matrices (PIM)	Quantitative	Extension of risk matrix with assignment of probabilities to risks under consideration	Probability index is calculated (probability of risk occurring times forecasted impact)	Risk exposure calculated with probability index	Might contain subjective judgments about input parameters; Extension possible using variability of input values, resulting in ranges for risk exposure

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Real Options (Benaroch 2001)	Quantitative	Maximizing the technology investment value by specifically evaluating all risks and corresponding (value increasing) options; calculation via log-transformed binomial method	Decision base for investment structure. NPV (active) calculated as NPV (passive) plus value of identified options	Options evaluated to control recognized risks	Focus on interaction of options and shadow options
Real Options (Ben-David/Raz 2001)	Quantitative	Based on a WBS, risk “events” are defined, probability impact matrices generated; and risk reduction tasks with associated costs identified; Total risk costs in objective function (expected + certain costs) are processed in iterative algorithm	Output is minimal overall total risk cost for set of risk reduction possibilities	Reaction options, established list of risk sources	Consideration of secondary risks and combination of risk reducing activities; Positive risk events included
Real Options (Bowman/ Moskowitz 2001)	Quantitative	Authors demonstrate limitations of standard real options analysis (Black-Scholes formula) for strategic decision making based on a case study of Merck &Co	Main limitations are fit of the underlying evaluation model assumptions (in calculation scheme and input data)	Within model	Suggestion given to conduct analysis with customized model and to thoroughly analyze the result from a strategic viewpoint

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Real Options (Bräutigam et al. 2003)	Quantitative	Incorporation of organizational and strategic considerations in real option evaluation; case study for e-commerce project uses log-transformed binomial calculation	Initial strategic evaluation of situation (within matrices); Option values counting for correlations	Uncertainty – option matrix and uncertainty – impact matrix	Correlations between individual options and between uncertainties considered
Real Options (Herath/Bremser 2005)	Quantitative	Introduce concept of “strategic value created” (SVC) to express the real option value; case study of pharmaceutical industry	Both NPV and SNPV calculated for case study to identify effect of flexibility	Calculation of strategic net present value (SNPV), i.e. NPV + option execution	Comparison of traditional NPV calculation and real option approach shows better results if flexibility to react (options) is considered
Real Options (Huchzermeier/ Loch 2001)	Quantitative	Focus on option “corrective action”; conditions examined which impact the value of flexible reaction; model based on dynamic programming	Overall project value and value of managerial flexibility via real option approach	Variability of 5 factors: market payoff, budget, performance, market requirement, and schedule	Results show that if certain conditions apply the value of managerial flexibility is reduced
Real Options (Luo et al. 2008)	Quantitative	Evaluation of effects on project value if hedging is considered for unique / technological risk; Comparison between real option calculation and real option plus hedging	Effective hedging can enhance the value of a project; over- or under-estimation of project values can be avoided	Technology and market uncertainties	Hedging approach implemented in order to avoid the subjective forecasts for required input data

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Real Options / Scenario Planning (Miller/Waller 2003)	Qualitative	Considering qualitative aspects of scenario planning and real option assessment	"Integrated risk management process" for overall portfolio on corporate level	Uncertainties and risks evaluated within assessment	Combining the advantages of scenario planning and real options in a qualitative analysis
Real Options (Santiago/Bifano 2005)	Quantitative	Case study of NPD project, covering decision tree and real option analysis Multidimensional variable for management process	Discussion base for expected actions in further development process	Technology, market and budget risks considered	Multidimensional view demonstrated within model for a specific development project
Real Options (Schneider et al. 2008)	Quantitative	Model for real options with MAD (Marketed Asset Disclaimer) approach which assumes an incomplete market (present value of project is market value); Case study of hybrid vehicle technology	Multi-dimensional decision trees – "strategy trees" for further evaluation	Market, project and research uncertainties considered	Generic, modular real option model established to grant broader usage / applicability
Real Options (Schwartz/Zozaya-Gorostiza 2003)	Quantitative	Model allows for changes in costs of project completion; Case study of IT projects (development and acquisition)	Value of investment (for development project) versus sequence of cash flows (for acquisition project) as outputs	Uncertainty in costs and benefits as parameters considered	2 models for highly volatile circumstances; Introduction of a "trend" for costs to complete the project

Method	Data Input	Application	Output / Result	Risk Consideration	Summary / Limitations
Real Options (Smit/Trigeorgis 2006)	Quantitative	Managing portfolios of real options via a "real option growth matrix" (displaying NPV and value of growth option); Extension with inclusion of game theoretical competitive strategies	Quantification and graphical display of current status and potential future state as well as competitors' moves as base for strategic decision making	Within assessment of growth options	Portfolio planning model for strategy decisions with focus on growth potentials which incorporates market / competitive considerations
Real Options (Willigers/Hansen 2008)	Quantitative	Real option evaluation for the pharmaceutical industry; Introduction of a least-square Monte Carlo model Focus on option to abandon project	Comparison of outcomes if different evaluation techniques are applied to identical data base	Market and technical risk	Increasing levels of uncertainty lead to different outcomes for the value of flexibility for the different models applied

5.2.4.4 Design Flexibility

Flexible, iterative PM processes in a fast changing environment allow for learning and selectionism (Pich et al. 2002). While learning is obtaining more information about unforeseeable uncertainty and quickly reacting to them, selectionism concerns developing multiple solutions, e.g. several prototypes in parallel, and finally deciding on the optimal solution. The latter approach can be referred to as contingency planning for the project (Olsson 2006), which is mainly influenced by the chosen strategy for technology commitment (Krishnan/Bhattacharya 2002). The development of several solutions or changes in features during the development process is facilitated by adoption of flexible technologies, e.g. simulation tools for rapid prototyping (Thomke/Reinertsen 1998). Design and technology flexibility have been studied for example for processes in the aero-engine development (Nightingale 2000), computer battery technologies (Krishnan/Bhattacharya 2002), development of integrated circuits (Thomke 1997) or for development in the automotive industry (Thomke 1998). The application of flexible technologies or computer aided design-tools lead to a better management of the risk of changes (Thomke 1997), especially as they enable faster and more design iterations at lower costs (Thomke 1998) or reduce the amount of required redesign loops (Nigthingale 2000) - both enhancing the quality of the final R&D output. With flexible processes a postponement of product definitions or specification freezes to a later phase in the PLC is possible, additionally benefiting from information gained in preceding phases (Bhattacharya et al. 1998). If solutions with differing technologies are developed in parallel, the commitment to one path needs to take place earlier, while for overdesigned products, i.e. considering different technologies in one development solution, the final choice can be further delayed (Krishnan/Bhattacharya 2002). However, the economic costs of changing a product during development are a sort of "upper bound" to the degree of flexibility, as the economic benefit from a change must always exceed the economic cost of conducting it (Thomke/Reinertsen 1998). Nevertheless, the appropriate degree of design flexibility and the timing of design freezes contribute to the success of projects as they facilitate meeting design objectives (Shenhar et al. 2002) and avoid the negative effect of plan changes or resulting changes in project objectives on the project success (Dvir/Lechler 2004).

5.2.5 Risk Monitoring, Control and Reporting

Regular periodical reviews are needed in order to reassess the current status of risks, react to changes, implement alternative responses (Hillson 2002) but also whether new risks arose in the meantime and how these influence the already identified risks and overall risk exposure (Ward 1999b). When a stage-gate-process is implemented to manage the project, the risk monitoring can be undertaken in gate reviews. Moreover, options need to be continuously assessed, monitored and judged (Mitchell/Hamilton 2007) as over the PLC new options evolve in the different stages and other options might be no longer present (Benaroch 2001). As the process is iterative, new risks or altered risk exposure requires new assessment and analysis of the changed situation. Reflective processes which can store the gained knowledge allow more flexible reactions within the project (Perminova et al. 2008). When the project is completed, reporting involves information gathering which risks and opportunities were present and about how an uncertainty was handled. The evaluation of the result further allows defining lessons learned which in turn can be considered for other projects (Ward 1999a).

6. Organizational Environment

6.1 Flexibility in Organizations

The real option thinking shows that it is appealing and can create additional benefit for firms to remain flexible in highly uncertain environments (Pender 2001). Further, a high degree of flexibility in development avoids the need for far-reaching forecasts, which might in many cases be inaccurate (Thomke/Reinertsen 1998). However, the value of flexible decision making through real option techniques is still not exploited sufficiently as corresponding methods are often not implemented by firms (Hartmann/Hassan 2006). The method needs to be understood by all people involved in the projects' decision making as well as senior management. Highly analytical solutions might lead to "black box" problems which make it impossible for decision makers to really understand the output. As people provide the inputs for all further evaluation, they need to be aware of how the various inputs interact and are processed by the model and finally need to judge the outcome and derive correct actions, consider strategic targets as well as the competitive situation (Bäcker/Hommel 2004). Recent articles therefore try to focus on models which are implemental and understandable by firms (Willigers/Hansen 2008, Schneider et al. 2008). Reasons for the low use of these methods in practice are that decision makers have not sufficient knowledge about how the models work, consider them as very complex to use and are in general satisfied with their existing risk analysis methods (Hartmann/Hassan 2006). Further, organizations are characterized by certain structures and processes which might not always allow for the required flexibility (Pender 2001). Therefore, the overall organizational characteristics need to support flexible process, structures and risk management (Miller/Waller 2003).

Especially for projects where high uncertainty is present and quantification of uncertainties is difficult, flexible management is necessary (Atkinson et al. 2006). Most organizations handle various different projects simultaneously and need to adopt management styles for these "temporary organizations within organizations" (Shenhar 2001), and reach an alignment to the overall corporate strategy in order to achieve successful project completion (Crawford et al. 2006). In multi-project environments organizations should establish environments which enable optimal coordination of activities as well as discovery of interdependencies and overlaps between teams (Danilovic/Sandkull 2005) while considering different objectives and trade-offs between performance criteria (Atkinson et al. 2006). The need for coordination of different tasks and information and at the same time allowing for fast reactions to unanticipated events require a "balance between order and chaos" (Geraldi 2008), i.e. the combination of controlling, mechanic operations with flexible, organic processes. Especially when technological uncertainty is high and when more parties are involved, more bureaucracy and formal processes or documentation are required to track and coordinate the variety of required activities (Shenhar 2001, Shenhar et al. 2002). On the other hand, multiple projects to handle and the inherent uncertainty of the projects require flexible processes (Olsson 2006). Geraldi (2008) therefore proposes a framework to deal with varying degrees of complexity and flexibility. Firms with creative-reflective organizations (highly uncertain projects and high flexibility) and mechanic-structured organizations (structurally complex projects and low flexibility) manage to fit the projects' characteristics to the organizational processes. However, the basic organizational set-up is influenced by the overall culture as well as human behavior.

6.2 Corporate Culture and Management Processes

The organization culture and the overall attitude towards uncertainty and risk influence the quality of uncertainty management and the way how risks are treated (Atkinson et al. 2006) and a "no negative feedback culture" can lead to under-evaluation of risk during assessment and implementation of exaggerated responses (McGrew/Bilotta 2000). Though risk management and real option applications can handle a large variety of unforeseen events which concern external or project-inherent risks, they neglect or cannot quantify internally generated risks which occur due to values and beliefs, rules, structures, cultures, behaviors or decisions and are linked to human behavior (Barber 2005). Decisions might therefore be biased, used data misinterpreted or alternative solutions neglected (McCray et al. 2002). Managers use their past experience and intuition and do not stick rigidly to processes but instead handle certain project situations by improvisation and informal decision making (Jaafari 2001). A flexible organization supports to benefit from this behavior (Leybourne/Sadler-Smith 2006). The matrix type organization or "cross-functional development teams" (Pons 2008) are most commonly used for project activities (Hyväri 2006), but can increase the complexity of interaction (Geraldi/Adlbrecht 2007) and give rise to different conflicts, e.g. about resource requirements, between functional and project managers or between managers of different projects (Laslo/Goldberg 2008). If the conflicting parties detect unrealistic conflicts which basically increase benefits for both parties, the organizational performance can be increased (Laslo/Goldberg 2008). Therefore, the matrix organization and project teams seem still to provide suitable structures for new product development projects, as a functional organization does not lead to satisfying performance and results for these projects (Larson/Gobeli 1989).

The underlying organizational form needs to be adequately flexible to manage the chosen or implemented project management process. Shenhar (2001) points out that with differing extents of technological uncertainty and system scope projects exhibit different levels of complexity. Therefore, the degree of formal, rigid processes on the one hand or flexible, adjusting processes on the other hand varies, i.e. "one-size-does-not-fit-all". Moreover, projects are undertaken within different organizational surroundings and have different historical contexts. Both factors need to be fully understood and considered in order to deduce appropriate management processes

(Engwall 2003). Nobelius (2004) distinguishes between five generations where R&D serves different purposes and has different shapes, e.g. focus on laboratory basic research, focus on platform concepts and fast time-to-market or focus on interaction and system integration for large-scale network R&D. Hence, processes and managerial approaches to project realization should suit and correspond to the type of R&D the organization is conducting. Therefore, an implemented stage-gate-process should allow for overlaps, flexible adjustments and still giving the basic guidance through the whole project (Cooper/Kleinschmidt 2007). All these factors underpin the necessity of project categorization systems which provide a mean to classify the projects in multiple dimensions and to provide on the one hand the holistic view of the project network but also to derive the optimal strategies for managing those (Crawford et al. 2006). Besides adequate processes to represent the overall strategy, the organization should provide a cultural environment which enhances innovative thinking and generation of new, maybe higher-risk ideas (Cooper/Kleinschmidt 2007). Usage of flexible design techniques as described above can help to control whether innovative solutions are finally implemental.

As a variety of other factors impact the overall success of projects, the next paragraph concentrates on the different criteria which are important to consider for successful project outcomes.

7. Project Performance and Success Evaluation

As the major objective of project and risk management is successful completion of projects, this gives rise to the obvious challenge to measure whether a project is a success or failure and to determine which attributes contribute to a successful project outcome as well as to success in the long run (Shenhar et al. 2001). The performance or success metrics of a project can be classified into profitability and impact measures (Cooper/Kleinschmidt 2007). Profitability metrics calculate the benefits or profit relative to the costs for R&D, evaluate whether internal profit objectives are met or profitability relative to competitors. Measures of impact include percentage of sales by completed projects, impact on sales revenues or annual profit, percentage of projects that became commercially and/or technically successful. A combination of both dimensions can provide businesses insight into the overall performance of completed R&D projects.

Additional difficulty in evaluation of project performance emerges as success is context dependent and a mixture of strategic and managerial variables, financial performance measures and subjectively evaluated judgments (Jugdev/Müller 2005, Shenhar et al. 2002). Moreover, different stakeholders have differing views about project success and therefore universal success criteria need to incorporate all possible aspects (Dvir et al. 1998).

The traditional "iron triangle" of success by fulfilling cost, time and quality objectives was recognized by many researchers as not being sufficient and representing a short-term measure (Judgev/Müller 2005, Shenhar et al. 2001, Atkinson 1999). For project managers these goals are crucial for their future reputation but for the overall business success the importance of budget and time objectives achievement, representing project management efficiency, decreases when projects are characterized by higher uncertainty (Shenhar et al. 2001). The probably strictest criticism of the iron triangle was articulated by Atkinson (1999) who described it as "two best guesses [cost and time] and a phenomenon [quality]".

The quest for defining factors which are critical to the success of projects led to a large variety of case studies and surveys among practitioners to derive the most important factors contributing to successful completion of their projects (Jugdev/Müller 2005). In their review on 63 articles about critical success factors (CSF), Fortune/White (2006) discovered that support from senior management, clear and realistic objectives as well as a detailed, regularly updated plan are most often cited in the research literature. A cross-industry study among different project types confirmed these factors as very important for practitioners, adding adequate resource availability to the most often stated success factors (White/Fortune 2002). The study revealed that risk management is a CSF for overall project success for only 50% of the surveyed, and is considered as important only by a few articles (Fortune/White 2006). Mostly the general CSF contain characteristics beyond the internal measure of project completion within pre-defined cost, time and performance objectives but include factors like clarity of goals (mission), management support, customer satisfaction, communication and personnel, technology availability, monitoring and feedback as well as trouble-shooting which vary in importance over the life of the project (Pinto/Slevin 1989). Moreover, critical failure factors were evaluated for different project types like R&D vs. construction (Pinto/Mantel 1990), or a list of failure factors derived from case study projects including for example ignoring the environment and stakeholders, weak leadership, no reviews, no fall-back options or ignorance of trade-offs (Pinto/Kharbanda 1996). McDonough/Spital (2003) found that unsuccessful projects occur if people are responsible for too many projects, budgets are inadequate and project managers and teams change frequently.

Beyond listing CSF independent of contextual influences, CSF are assessed with regard to different perceptions of involved groups. Lipovetsky et al. (1997) in studying Israeli defense projects evaluate that benefits to the customer are most important for all different groups of stakeholders. Atkinson (1999) also considers the wider context of project success and extended the iron triangle to a "square-route", including benefits to the organization, to the stakeholders and an information system covering e.g. validity or reliability. Different viewpoints distinguishing between micro (iron triangle) and macro (satisfaction by stakeholders) contains the framework by Lim/Mohamed (1999). This leads to the important distinction between project and project management success. The former can only be measured on a longer-term and not immediately after completion of the process, whereas project management success is part of the overall project and can be assessed with internal criteria (Munns/Bjeirmi 1996). The authors state that "a project can be a success despite a poor project management performance". For project management success risk awareness and management techniques are important (Cooke-Davies 2002). Moreover, Raz/Michael (2001), studying firms in high-tech industries in Israel, found a positive relationship between RM tool usage and project management performance in terms of meeting budget and schedule goals. Still, determining the effectiveness of a RMP poses on the one hand the challenge to estimate whether important risks were identified correctly, and whether an adequate strategy for the consequence was implemented, i.e. that no over- or under-evaluation of risk and consequence occurred. On the other hand it involves the more complicated task to assess a consequence which would not have happened in this way if the mitigation strategy would not have even been implemented (McGrew/Bilotta 2000).

For assessment of project success, in addition it needs to be considered that the factors are not identical for all kinds of projects (Dvir et al. 1998), and certain managerial factors have different importance depending on the project type and context (Shenhar et al. 2002). In order to include external criteria and show the interrelations between the factors, Belassi/Tukel (1996) propose a grouping into factors related to the project, to the project manager and team, to the organization and to the external environment. The authors provide a framework which shows how the groups are related and contribute to success or failure. As for several CSF there is no agreement among authors whether they contribute to success or failure, and due to the high amount of different factors listed in the literature, Balachandra/Friar (1997) propose to include the contextual variables nature of innovation (incremental - radical), nature of technology (high - low) and nature of market (existing – new). The resulting "contingency cube" helps to concentrate on success factors which are most important for the respective block the project fits in. A multi-dimensional framework which also distinguishes among context variables was developed by Shenhar et al. (2002). The authors clustered 13 success measures into the three groups of meeting design goals, benefit to the customer as well as benefit to the organization and future potential. This allows deriving the effect of five managerial dimensions (idea origination/project milestones, planning/control, policy/design considerations, organizational factors, documentation/reporting/management policy) on the three groups of success, while including a project type distinction along two levels (low-high) of technological uncertainty and system scope complexity. The major outcome is that success factors for high uncertainty projects include thorough identification of milestones and of WBS, design considerations during development, formal documentation and policies for quality, reliability and redundancy as well as customer participation. Further, Shenhar et al. (2001) showed that the dimensions of business success and future potential (long-run profit considerations and market positioning) gain in importance for projects with high technological uncertainty and projects which need a longer time-frame for completion. Successful R&D projects can therefore be facilitated by implementing strategies for real-time management of the existing complexities and decision making which is driven by strategy (Jaafari 2001).

Four strategic criteria for project success which need to be coexistent were summarized by Turner (2004). The first condition is derived from Wateridge (1995) and emphasizes the importance of agreed upon objectives with the stakeholders and frequent reviews. The other three criteria concern the owner–project manager relationship and were originally evaluated by Müller (2003). The work environment must be highly collaborative and seen as a partnership to avoid principal-agent confrontations. In addition, an adequate empowerment of the project manager by the owner is important, i.e. allowing for flexible risk and uncertainty reactions while still giving guidance. The last criteria demands for regular performance reviews and reports.

Overall, the key factors for success in R&D projects go beyond the thorough management of risks, and are a combination of the business strategy in the competitive environment, the implemented process, the organization climate including team composition and leadership style, and adequate resource commitments in connection with portfolio management (Cooper/Kleinschmidt 2007).

8. Conclusion

Management of R&D projects and the inherent risk management activities in order to reach a successful project completion pose a large variety of challenges on practitioners. Though research about promising R&D project selection techniques as well as risk management processes for monitoring and effective response planning is continuously expanded, projects in reality are still often failing to reach the set objectives.

Real option thinking and the respective models to incorporate managerial flexibility into investment decision-making which are proposed by researchers are promising evaluation methods in changing R&D project conditions. However, comprehensive usage of these methods in organizations is not common yet, and the research focuses on individual case studies where the implementation of a real option model in a specific situation is assessed. Therefore, there is the need to adopt or simplify the existing theoretical models which are mostly calculatory extensive in order to being more easily implemental and understandable in real project conditions. Moreover, the assessment of future project performance or prospective investment opportunities still relies on the required model inputs and forecasted values. Whether these data really materialize remains a main uncertainty and there is always the indeterminable possibility that originally expected future states will not become real or turn out to be wrong. These situations require organizations which allow for and are willing to implement harsh changes during project execution, as for example the option to completely abandon the project or change action in midcourse can then be exercised.

The overall project result is dependant on various interacting factors which often cannot be examined before or during the project. The real, final influence of some attributes might be indeterminate even after completion. Corporate values, human behavior, unique project conditions, and a changing environment all contribute to the difficulty to generalize success strategies. The complex interrelations of different, sometimes quite small or originally neglected factors turn it impossible to derive a "one-and-only" management strategy which constitutes the recipe for successful R&D projects in all situations. However, there are several factors and methods which enhance positive project performances and which are definitely needed for a satisfying and successful project and risk management.

The respective corporate strategy regarding R&D activities is the driving force for subsequent decisions about project selection and realization during execution. If organizations fail to allocate their resources optimally to prospective projects with high future potential, the growth of the business as well as the position in the competitive environment are jeopardized. Projects which are aligned to the firm's strategy, fit into the optimal portfolio, and additionally are supported by senior management might therefore have a higher probability of successful completion. As a consequence, as early as with the very first evaluation of a prospective project, companies determine the compatibility with general corporate objectives and exert already a certain influence on the possibility for a good project performance. Firms should not avoid high risk projects, but instead conduct different kinds of projects according the chosen strategy, and implement adaptive management processes for various project types, i.e. with low or high uncertainties.

The methods used for R&D project selection as well as for risk and performance evaluation during execution need to be customized to the respective needs of the company, and involve both qualitative and quantitative aspects. Adoption of too general models might lead to neglect of important firm-specific criteria or requirements. Further, usage of only one single method might as well lead to a biased view and not being able to provide a holistic assessment of the R&D projects which are undertaken.

R&D projects require effective and efficient processes to manage inherent and evolving risks and opportunities. Therefore, organizations need to find a balance between conducting actions to avoid negative occurrences, and enhancing possible positive effects of uncertainties in order to ensure an overall successful project completion. The implemented processes for project and risk management need to support required iterative loops due to changing conditions and new situations.

As a very important success factor is the execution of regular reviews and frequent evaluation of the situational influences and the project performance, the underlying processes need to provide specific milestones with agreed upon expected project achievements. Moreover, the implemented processes need to support fast and flexible reactions if the risk exposure changed unfavorably or positively, or a different response is required to cope with an evolving situation. Though the processes should govern the single steps during development, successful completion can only be reached if there are not too rigid or inflexible guidelines. This apparent trade-off is probably the most important challenge organizations face when deciding on the structure of project and risk management processes. On the one hand, firms require repetitive and general processes which can be used for all projects within the company. However, as flexibility and fast decision-making resulting from changed situations is indispensable during R&D project execution and a very important requirement for positive project performance and the success of the overall project, it is highly important not to be caught by a fixed, unchangeable process.

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10. Appendix

10.1 Abstract in English

The aim of this thesis is to study and assess the processes, means and methods to manage risks in R&D projects. As many different sources of risks and uncertainties for R&D projects exist, organizations need to implement management processes and techniques which allow reacting in an effective and efficient way to changed situations and evolving future uncertainties.

The research question focuses on the major project risks and relevant methods firms can use to enhance successful project results, i.e. prevent negative and foster positive impact on the project outcome. A thorough literature review is carried out across the project management process and the related risk management methods with regard to identification, analysis and evaluation as well as response planning and implementation.

The study also evaluates project selection methods with the goal of choosing the optimal, balanced portfolio containing high and low risk projects, being aligned with the corporate strategy. Further, the required organizational structure and culture is assessed, and how strategy and process flexibility contribute to an effective uncertainty management. Additionally, performance measures and project success evaluations are examined.

10.2 Abstract in German

Das Ziel dieser Diplomarbeit ist, verschiedene Prozesse und Methoden des Risikomanagements in R&D Projekten anhand einer ausführlichen Literaturrecherche zu analysieren sowie diverse Modelle zu evaluieren, welche den erfolgreichen Abschluss von Projekten fördern.

Das Hauptaugenmerk ist dabei auf den Prozess des Risikomanagements als Bestandteil des Projektmanagements gerichtet, wobei geeignete Methoden zur Risikoidentifikation und -analyse sowie hinsichtlich der Entwicklung von strategischen und operativen Reaktionen auf entstehende Risiken dargestellt werden.

Des Weiteren werden Methoden zur Projektauswahl und Portfolioplanung beurteilt. Langfristig erfolgreiche Unternehmen verfügen über ein ausgeglichenes Projektportfolio, welches Projekte mit unterschiedlichen Risikointensitäten beinhaltet. Diese Firmen führen einerseits Projekte durch, welche kurzfristig Gewinne erzielen, investieren jedoch zeitgleich in riskantere Projekte, deren zukünftige Erfolgschacen unsicher sind.

Erfolgreiches Risikomanagement kann nur entsprechend implementiert werden, wenn notwendige organisatorische Voraussetzungen gegeben sind. Da ein hohes Maß an Flexibilität erforderlich ist, um in Projekten auf wechselnde Rahmenbedingungen oder Gegebenheiten reagieren zu können, müssen die von der Organisation vorgegebenen Prozesse variabel angepasst werden können. In diesem Zusammenhang wird auch dargestellt, wie die generelle Organisationsstruktur und –kultur sowie die vorgegebene R&D Strategie des Unternehmens die Prozessdurchführung beeinflussen können.

Abschließend wird die Entwicklung von generellen Erfolgsfaktoren zu differenzierteren Systemen dargestellt, und welche Aspekte – neben Risikomanagement - für einen erfolgreichen Projektabschluss notwendig sind und beachtet werden müssen.

10.3 Curriculum Vitae

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