Portfolio Approach for Intellectual Products

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Abstract: In the following we present a model and an according framework for the selection and the evaluation of research and development (R&D) projects, that accounts for the *risk* as well as the *utility and the "profitability"* of these projects. Because of the highly novel and innovative character of R&D, for projects from this domain must also, by definition, exist a high level of uncertainty with respect to the potential outcomes of the projects. The success or failure of an R&D project is difficult to argue as there are many more aspects to be taken into account than just having met a predefined project target. A multi-dimensional measure needs to be used that also considers aspects like the increase in knowledge, or environmental, or social impacts of such projects, complementary to the financial aspects always to be observed. We propose a technique to measure the "knowledge" acquired within an R&D project to be based on definitions taken from information theory. With the help of the Real Options (RO) model, our multi-dimensional measure is used in the process of evaluating R&D projects with respect to their risk and uncertainty. We will define the terms *risk* and *uncertainty*, which are frequently used in an un-precise and interchangeable way, on a sound statistical foundation.

Keywords: research management, technology management, decision analysis, cost benefit analysis, R&D portfolio management, risk management, intellectual products. Intellectual capital, intangible assets, real options, Knapsack problem, project interdependencies, synergies, knowledge valuation, portfolio analysis, Multi-Attribute Utility analysis

Introduction

The generation of intangible but "formalisable" goods, in specific information products, following well defined rules of design, such as software or blueprints of R&D results, is usually modelled by means of singular projects or repeatable processes [1]. Processes used to generate formalisable intellectual products are independent from the type of result. I.e. from a managerial point of view there exists no difference in principle with respect to the subject of any R&D work, either it is material or not (as is software), as long as the generating processes and their documentations follow the same models of stepwise or iterative progress towards more or less precisely pre-conceived results. We also take it for given, that in organisations running R&D processes, an established culture of project & process management and the notion of process maturity levels has already been adopted so that there exists and is applied an explicit set of formalisations of projects and processes.

The environment in which our "decision method" has been developed is a relatively large R&D organisation which also could be as well a product oriented software company or, as in our case of a research organisation, employing several hundreds of R&D personnel and continuously running several hundreds of R&D projects - in our case ~200 - which each needs to have a minimal size of three person months and may range up to many – in our case at a maximum of eight - person years. This definition is not made for any formal reason rather than for the insight gained, that an implementation of our approach needs a minimum level of investment which only pays off for larger project organisations.

We look at organisations which, either by their mission or by their strategy, are devoted to continuously create new technological products either for their customers following a contract R&D model, or it is a business driven organisation which, for the sake of its strategic growth, is obliged to continuously invest into new products and therefore is forced to permanently take decisions on investments in its R&D. The question on stage is, how such an organisation can make sure that the totality of its decisions will safely lead to the fulfilment of its anticipated goals. Our challenge was to find a better approach to answer the classical question on how to optimise between risks of failure of R&D projects on the one side, and, on the other side, to generate “best” exploitations of project results thereby producing a maximum in RoI (Return on Investment).

To master this trade-off problem, so far methods such as classical RoI (Return on Investment) estimations as are e.g. Discounted Cash Flow (DCF) or a Net Present Value (NPV) estimation have been used. The introduction of “Option Pricing” to IT products under development raised a discussion if such methods analysing “options” of alternative R&D projects can add remarkable quality to the decision making on investments in R&D. The challenge is, that the set of R&D projects envisaged to be invested into shall be configured in such a way that an optimal portfolio is constituted, where the objective is to maximise RoI and to minimise risk of no or negative RoI. Option methods for defining RoI by means of Portfolio Analysis have been applied since long for the analysis of financial stocks in order to identify their value with respect to the stock markets, i.e. for optimising portfolios with the aim to increase profit and value. Applying the same philosophy to portfolios of R&D projects instead has been suggested for IT projects by John Favaro [2]. We embarked and extended on his idea with the impetus to find a generally applicable, practical method for decision takings in R&D organisations which already have some formalised decision making system in place which they use regularly in planning their R&D budget for a next investment period. The new dimension we are able to add to classical decision makings based on Option Pricing-induced portfolio optimisation have been some insights recently gained by Bettina Schauer [3] at the “Austrian Research Centers” (ARC), a ~ 1200 employees R&D conglomerate serving as our case study organisation.

For its management ARC applies a complete “Method & Tool System” as is shown in **Fig.1**. In a combined top-down and bottom-up way the organisation’s vision, mission and strategy, its derived objectives modelled by means of Balanced Scorecard, the then decided R&D programs and the larger set of specific projects defined in a bottom-up way with the mission to fulfill the strategic goals are re-redesigned in annual cycles. Please observe that besides the approach presented in this paper, other methodogical inventions in order to improve the decision quality have been made in this framework as well, in specific on issues of “measuring” the growth of Intellectual Capital of the respective organisation, which is reported elsewhere [4].

Decision making on R&D programs in the case of ARC is a multi-facetted and multi-influenced process as, by its mission, all stakeholders, i.e. the government owning the majority stake, industry also being an influential shareowners’ group, the customers’ community, the top and middle management, all employees and cooperation partners are invited to participate in this process. In short: No other type of organisation producing intellectual goods could demonstrate to be more complex in this respect. In a rough picture, decision making on projects so far follows a systolic and diastolic process throughout different levels of decision instances and responsibilities **(Fig.2).** Although such a complex and multi-influenced process is assumed to avoid risks resuming from bad decisions, no checks on the economic validity of such decision making have been made so far, where the target value must be long term value increase and short term risk avoidance as well as benefit maximisation.

Evaluation of R&D Projects

In order to evaluate R&D projects for the selection into an R&D project portfolio an objective and deterministic valuation and selection process is required, that guarantees a most comprehensible strategy for making such investment decisions.

The success or failure of an R&D project is difficult to argue as there are many more aspects to be taken into account than just having met a predefined project target. A multi-dimensional measure needs to be used that also considers aspects like the increase in knowledge or environmental or social impacts etc. of the projects, complementary to the financial aspects. This multi-dimensional measure in each dimension includes a multitude of criteria the values of which are accumulated to one scalar utility value combined with multi-attribute utility analysis. This utility value is used to select a portfolio of projects so that the total utility is maximised and at the same time satisfies certain constraints concerning the always limited resources available. The portfolio selection process is implemented using a dynamic programming solution for the so called “Knapsack problem”:

Given a Knapsack of Capacity C_{max} being a limited resource, such as limited financial R&D budget, and n Objects representing projects, the question is: what is the optimal set of objects to be put into the knapsack in order to achieve to the peek of the mountain, in our case the maximum profit? Applications of the 0/1 Knapsack problem are very well known in the field of operations research. For example, a manager having various choices of investments with expected profits, but only a limited amount of money to invest, can apply the Knapsack algorithm to select the optimum projects in order to maximise the profit. Note that the term “0/1” refers to the fact that a project can either be selected or not, thus investing in parts of a project is not possible. The 0/1 Knapsack is an integer problem. The classical solution to the 0/1 Knapsack problem basically searches through all 2^n subsets of the set of n projects.

Therefore the complexity grows exponentially with the number of projects. Alternatively the dynamic programming solution to the 0/1 Knapsack problem calculates the optimum with linear complexity. The restriction to the dynamic programming solution that investments as well as the limits must be integer values is irrelevant for practical applications. Unfortunately the original dynamic programming solution to the 0/1 Knapsack problem does not allow for interdependencies between projects.

To consider interdependencies, synergies and redundancies between the projects within the selected portfolio, the dynamic programming approach for the Knapsack problem is extended in order also to allow for various kinds of interrelations, as are (see **Fig. 3**):

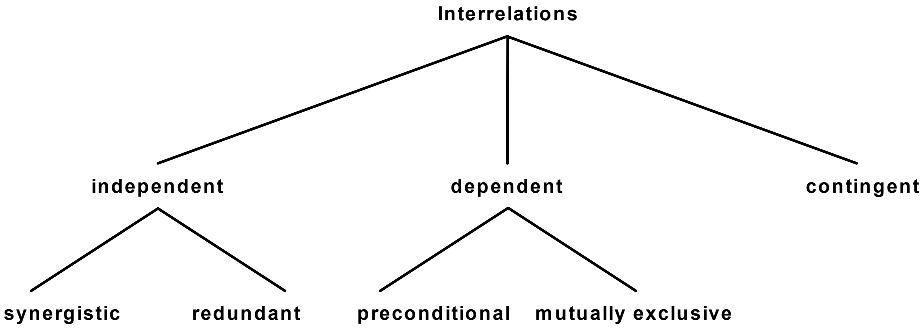

Figure 3:"Hierarchy of Project Interrelations"

Multi-dimensionality of R&D Projects

Besides monetary issues a prominent aspect of R&D projects is that in most cases they are undertaken with the aim also to gain knowledge in a certain domain. R&D projects are performed with the goal to use the knowledge gained for further follow-up projects, but also for the creation of networks, communities, publications etc. which are major success criteria for R&D projects. As a consequence it is mandatory that the evaluation process of R&D projects does not entirely focus on financial aspects, but also takes the multi-dimensional character of

R&D projects into account. A project which is considered to be a loss with respect to the financial RoI can be esteemed to be highly successful with respect to the knowledge gained within such a project, which again can be the basis for subsequent projects then being financially successful because of the input contributions of the former project. Thus the success criteria of R&D projects naturally are multi-dimensional and the focus can not only be on the financial RoI of the project only. For the sake of simplicity we assume the dimensions to be independent of each other. Examples for such further aspects worth considering are environmental, social or ethical impacts of R&D projects in perspective.

A Note on Measuring Intellectual Capital

When trying to estimate the *value of knowledge* gained within an R&D project, some special characteristics of the value of knowledge must be taken into account:

- Knowledge is bound to an individual or an organisation. Thus it follows that knowledge per se does not exist by itself.
- Under the assumption, that the context and the external references of a knowledge constitution are not changing, the level of knowledge of an individual or organisation only increases and never decreases, not even if the relevant information is given away to other individuals or organisations. This implies that one has gained knowledge within say a software project even if it turns out that it is not possible to develop a certain result or that a method is not applicable or that it is generally impossible to solve a problem as perceived.
- The “dissemination of knowledge” is relatively cheap in comparison to the value of knowledge.
- The convertibility of knowledge is a special issue; there exist cases in which knowledge can be “bought”, eg. by hiring people or by paying licenses. On the other hand there exist cases in which this is not possible, because the necessary information simply does not yet exist.
- The process of gaining knowledge usually is time consuming and it cannot be speeded up just by adding resources.

Data by definition are “objective” and can be stored, transferred and measured easily. *Information* can be gained from the data. This depends on how the human being interprets the data using his current level of information. Thus *information is subjective* and the same data can provide different information to different human beings. Furthermore information is independent from its representation. Knowledge is even more abstract, because it involves the processing of information within the context of knowledge the human being has already acquired. From these arguments it follows that knowledge according to our definition cannot be divided and neither be “stored”.

Following Shannon’s information theory [Claude E. Shannon and Warren Weaver [5]], the information content h of a message is given by:

$$h = ld\frac{1}{p}$$

where p refers to the probability of expecting this message and the binary logarithm scales the information content, that becomes 1 for $p = 0.5$. The information content is measured in bits.

Shannon’s information theory can also be transformed and applied to knowledge. The subjective character of knowledge can be expressed by using *expected values*, which *in turn* refer to expectations of individuals. Referring to the value of knowledge it is important to mention that the information content does not say anything about how *useful* the information is, but should rather be regarded as a measure of complexity. Thus one could say that a higher h implies a higher level of complexity but this does not necessarily mean that the analysed project is more useful than one compared to it with other qualities.

Risk and Uncertainty

As it was already mentioned above, R&D projects are characterised by high risk and uncertainty. Unfortunately in literature these terms are frequently used in interchangeable ways or, even worse, are not even defined at all. When determining the risk and uncertainty of R&D projects, or, in extension also of whole R&D project portfolios, it is mandatory to define these terms in a way that has a meaning with respect to the R&D context.

Risk can be defined as the probability of an undesired event e happening multiplied by a measure of the damage caused by that event. Considering R&D projects the damage caused is in most cases limited, because from a financial point of view the maximum damage is limited to the investments C made so far. Thus, the risk is proportional to the probability of the occurrence of that event. We define the $100\lambda\%$ risk of a project with respect to the probability of the project's performance being less than $100\lambda\%$ of the expected performance in any dimension k. The $100\lambda\%$ risk corresponds to a Value-at-Risk (VaR) with a confidence level of $1-\lambda$ as defined by Benninga and Wiener [Benninga and Wiener [6]]. It is assumed that the probability of the project's performance follows a Normal Distribution. Due to a lack of available data the mean and deviation of this distribution can be derived from experts' estimates of the performance. To be precise, the risk as defined above is multi-dimensional as with the investment C. Thus besides the financial risk we can also define environmental risk. However there is no risk for the dimension of knowledge as by definition any loss of knowledge is not possible by definition.

Note that every expert is requested to value a project only with respect to his/her own core competence, thus different experts may be involved such as from finance, research, management, knowledge etc. and their number may vary. It is self evident that the number and quality of such experts takes influence on the quality of the decisions to be taken.

Interpreting these experts' estimates as a sample of size n of the performance, we define the uncertainty of degree κ of a project's performance with respect to the dimension k as the probability of the performance differing more than $100\kappa\%$ from its expected value.

Real Options

The theory behind Option Pricing has turned out to be a most successful valuation method in the world of finance and we regard it also as a promising approach for the evaluation of R&D

projects. Introducing "option thinking" into the valuation process for R&D projects stems from the idea that there are a couple of similarities between the characteristics of real options and R&D projects, as are high risk and uncertainty with respect to the expected RoI. Due to the highly novel and innovative character of R&D projects also the flexibility to react to changing situations should be incorporated into the valuation process, which is automatically assumed when regarding R&D projects as real options. The options approach provides the possibility under analysed conditions to transfer a project on hold or to delay it. Thus status can be released, i.e.the project can then be continued if conditions analysed turn out to be favourable and if not, the project is due to be cancelled. To be precise this refers to regarding a project as the European definition of option.

Under the assumption that the performance of the underlying asset follows a logarithmic Normal Distribution, the call value[1] of the real option can be determined using the well-known Black-Scholes formula [7]:

$$\textit{Value of call} = S\, e^{-yt}\, \mathbf{N}(d_1) - Ce^{-rt}\mathbf{N}(d_2)$$

$$\text{with} \quad d_1 = (\ln(S/C) + (r - y + \sigma^2/2)t) / \sigma \sqrt{t}$$
$$d_2 = d_1 - \sigma \sqrt{t}$$

where $\boldsymbol{N}(.)$ is the cumulative Normal density function, S is the present value of expected cash flows, C is the present value of the investment cost, t refers to the project duration, r is the riskless interest rate, y corresponds to dividend payments and σ refers to the deviation of the experts' judgements.

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[1] A call option on an asset gives the right, but no obligation, to acquire the underlying asset by paying a pre-specified price — the exercise price — on or before a given maturity. A put option on an asset gives the right, but not the obligation, to sell the underlying asset and receive the exercise price.

Project Interrelations

In addition to the multi-dimensional success criteria and taking into account the projects' risks and uncertainties, a further important aspect for the portfolio selection process is the consideration of interdependencies, synergies and redundancies between projects, refer to **fig. 3**. Two projects are interdependent if the result of one project is a necessary precondition for undertaking the other project. The creation of knowledge networks within an organisation can cause synergies between projects, that cause benefits additional to the results of the synergistic projects. Furthermore it can be reasonable to undertake redundant projects with the same or a similar research goal simultaneously in order to reduce the risk of achieving the expected results at all.

Portfolio Selection

For the optimal selection of projects for a portfolio with limited resources, the total utility of the portfolio needs to be maximised. This corresponds to solving the above introduced Knapsack problem for which a dynamic programming solution is at hand. Considering projects interrelations we have to be aware that the portfolio's total utility is not additive. The projects and their interrelations can be mapped to a graph, with nodes corresponding to the projects and edges corresponding to the interrelations between them. Clusters of interrelated projects correspond to connected components of the graph. For each cluster the optimum subset of projects has to be determined fulfilling the constraints caused by dependencies and interrelations.

The statistical distribution of probability of the success of a portfolio of independent projects converges towards a Normal Distribution, the deviation of which equals the mean value of the deviations of the single projects divided by the number of these projects. As uncertainty grows monotonically with the statistical deviation of the estimated success to be expected from a portfolio, it follows that the uncertainty of the success of a portfolio of projects can be decreased by adding further projects to the portfolio – a fact which is intuitively clear.

Risk and Utility Evaluation Framework

The functionality of the Risk and Utility Evaluation Framework for R&D portfolios is to support decision makers with objective criteria for selecting R&D projects under limited resources and arbitrary interrelations. Input parameters are experts' estimates on the projects' success concerning the various dimensions, the available resources and interrelations as well as synergies and redundancies. Interrelated projects are grouped in clusters τ by the portfolio selection module. The risk and utility evaluation framework, see **fig. 4**, selects a portfolio that maximises the expected utility U considering the constraints and dependencies. Total risk $\rho_{\lambda,k}$ and uncertainty $\delta_{\kappa,k}$ of the selected projects are computed simultaneously. Although the evaluation and interrelations of the projects refer to the various dimensions the selection process is based on a scalar utility measure. The utility itself is determined by the call values $v_{i,k}$ of the real options model (RO) for every dimension of a single project π_i. These call values are determined using the statistical means $\mu_{i,k}$ and deviations $\sigma_{i,k}$ of the experts' estimates. For each portfolio the call values $v_{i,k}$ of the selected projects are accumulated and the portfolio's utility is determined using *Multi-Attribute Utility Analysis* (MAUA), thus delivering the ultimate portfolio's utility measure U.

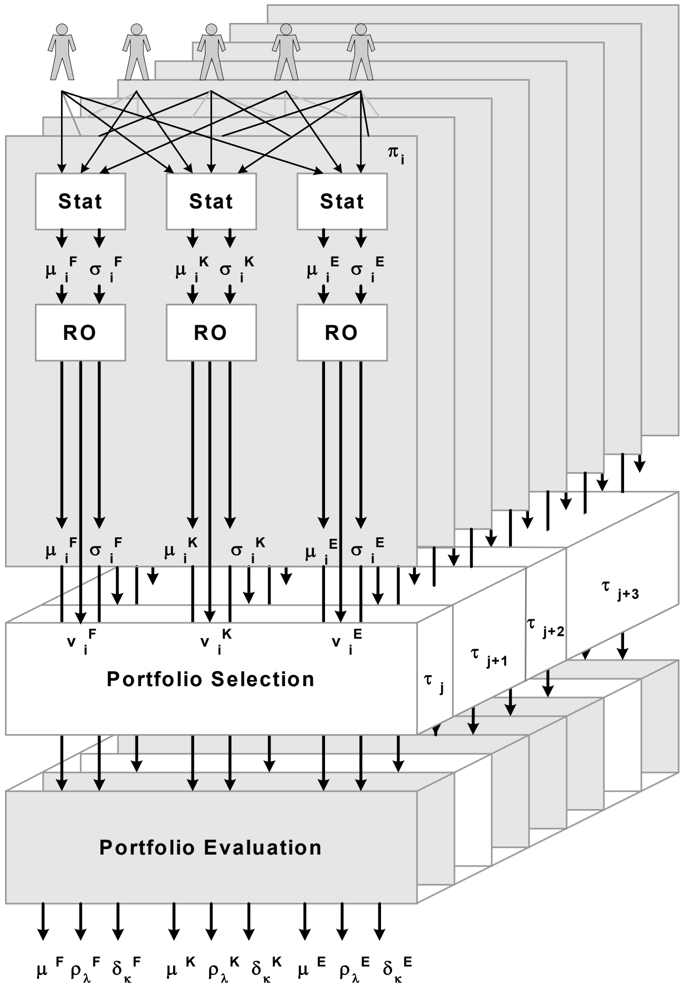


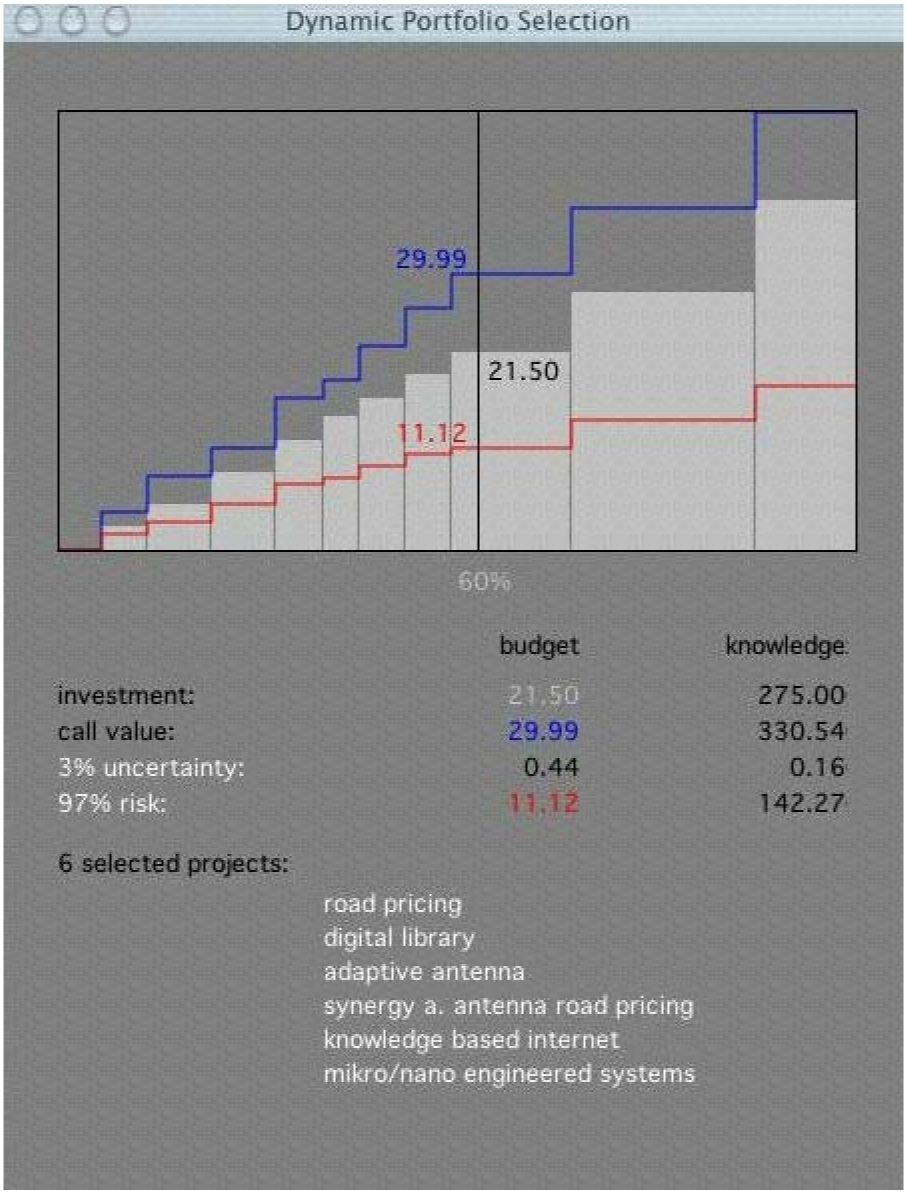
Figure 4: "Design of the Risk and Utility Evaluation Framework for R&D Portfolios"

Abbreviation	**Description**
π_i	Project *i*
$\mu_{i,k}$	Mean of experts' success estimates for dimension *k* of project π_i
$\sigma_{i,k}$	Deviation of experts' success estimates for dimension *k* of project π_i
$v_{i,k}$	Call value of dimension *k* of project π_i
$\rho_{\lambda,k}$	λ% risk of dimension *k* of selected portfolio
$\delta_{\kappa,k}$	κ% uncertainty of dimension *k* of selected portfolio
F	Dimension finance

K	Dimension knowledge
E	Dimension environment
τ_j	Cluster j of interrelated projects

Table 1: “Legend for Figure 4”

The dynamic programming solution to the 0/1 Knapsack algorithm allows for comparing financial call values (blue line) and financial risks (red line) for various financial investments (grey bars):



	budget	knowledge
investment:	21.50	275.00
call value:	29.99	330.54
3% uncertainty:	0.44	0.16
97% risk:	11.12	142.27

6 selected projects:

- road pricing
- digital library
- adaptive antenna
- synergy a. antenna road pricing
- knowledge based internet
- mikro/nano engineered systems

Figure 6: "Screenshot of the Risk and Utility Evaluation Framework for R&D Portfolios"

Conclusions

Under the following assumptions…

a) The valuation of a portfolio of intellectual projects follows multiple objectives…

b) The success of intellectual projects is usually hard to predict…

c) Innovative and novel intellectual projects are inherently risky and uncertain…

d) Selecting intellectual projects for a portfolio has to take into account interrelations between the projects as are: dependencies, synergies and redundancies - leading to covariabilities of the successes of the interrelated projects…

… we suggest a statistical model as most appropriate regarding the project's utility as a random variable with according mean and variance. Both risk and uncertainty grow monotonically with the statistical deviation of the estimated success to be expected from a portfolio.

The real progress achieved by our project-portfolio-optimisation-method based on our experience at the ARC R&D organisation is that the results confirmed and even proved some known existing intuitive insights of experienced R&D managers:

e) The statistical distribution of probability of the success of a portfolio of independent projects converges towards a normal distribution, the deviation of which equals the mean value of the deviations of the single projects divided by the number of these projects
f) From c) and e) above follows that the risk and the uncertainty of the success of a portfolio of projects decreases with the number of independent projects.

It is important for the project manager to realise that by adding independent projects to a portfolio the portfolio's risk can be diversified. On the other hand adding interrelated projects allows for synergistic effects increasing the portfolio's utility.

An open issue in this research agenda is to integrate multiple objectives when modelling a project portfolio by means of a multi-dimensional distribution function and thereby to generalise the Black-Scholes formula [7] so far used for the valuation of real options also for other types of portfolios.

What is important to state in view on future work on advanced RoI models for R&D is, that projections in R&D cannot and shall not only be measured with respect to their avoidance of risk and raising economic benefit only. Intense and wrong minded restrictions by reducing any decision making on R&D projects to these two dimensions only definitely limits the space and motivation for new invention. At ARC in the years 1999-2003 we have kept open some space for innovation projects called “Innovation Labs” as well as “New Initiatives” in the range between 8% to 20% of the annual R&D budget which did not need strict justifications. These projects were intended for letting new ideas crossing several disciplines emerge without asking for their justification, an approach which may be called basic research or, better, “curiosity driven” but nevertheless oriented (or directed) research. In this sense, our method may also well serve to better understand the borderline between basic research and applied R&D, taking risk and uncertainty as basic parameters for definition.

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G.R. Koch is a computer scientist with degrees from Karlsruhe University. Since recently he is professor at the Danube University in Krems, Austria. Having started as a software engineer, today he is an expert in theory and practice of R&D management. After a career as managing director of German software companies, he became the Founding Director of the European Software Institute (ESI) in 1993. In 1998 he was engaged as the General Director of the Austrian Research Centers, Vienna and Seibersdorf. He is also chairman of the board of a publicly noted IT company

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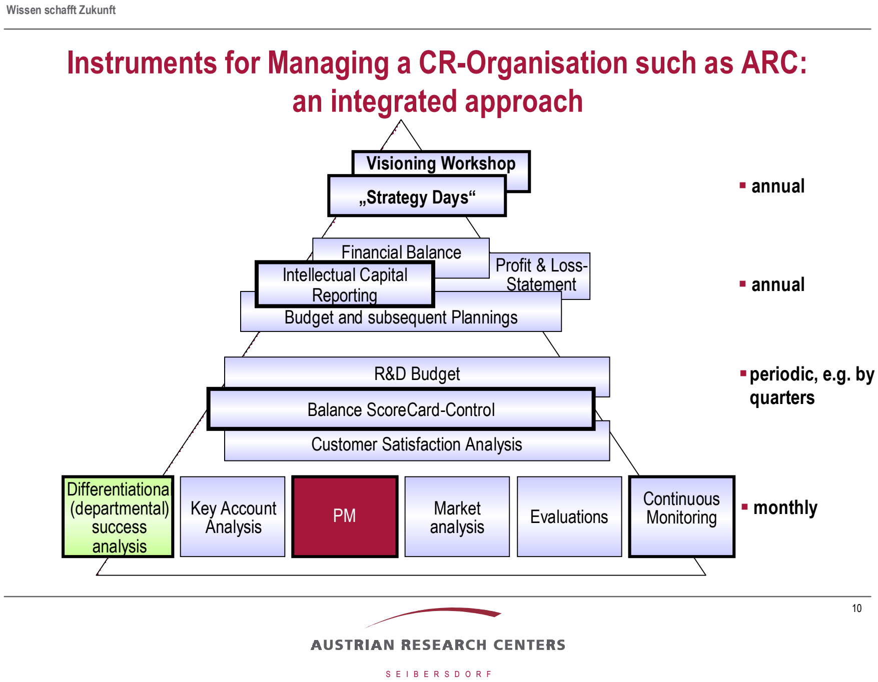
Figures

Fig. 1 Instruments for Managing an R&D-Organisation



Wissen schafft Zukunft

Instruments for Managing a CR-Organisation such as ARC: an integrated approach

Visioning Workshop
„Strategy Days“

- **annual**

Financial Balance
Intellectual Capital Reporting
Profit & Loss-Statement
Budget and subsequent Plannings

- **annual**

R&D Budget
Balance ScoreCard-Control
Customer Satisfaction Analysis

- **periodic, e.g. by quarters**

Differentiationa (departmental) success analysis
Key Account Analysis
PM
Market analysis
Evaluations
Continuous Monitoring

- **monthly**

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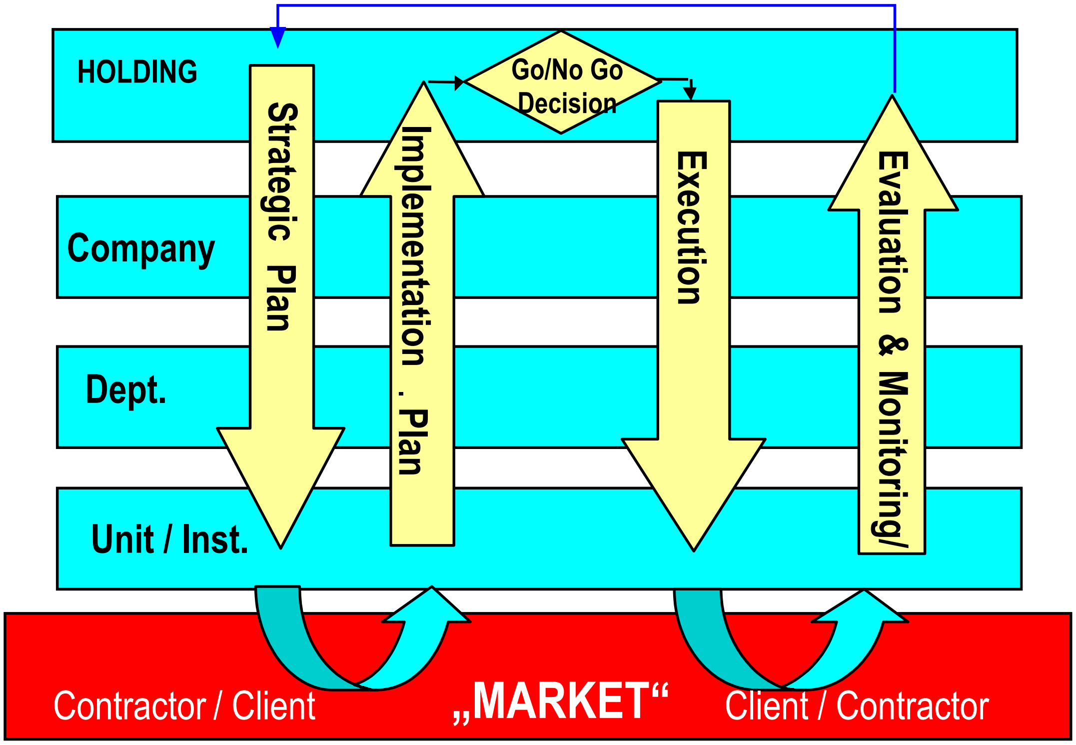
Fig. 2 Processes for planning & control of R&D programmes at ARC



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