# Risk Optimization for R&D Project Portfolios

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*ABSTRACT*

*R&D projects typically exist in an environment that requires management to allocate resources (staff, space, and funds) across a limited number of projects. This process can have a significant impact on the future growth and profitability of the business, both positive and negative. The method presented includes simulation techniques to model and estimate the aggregated risk exposure. It allows a risk based approach to evaluate portfolios of activities or projects under the presence of uncertainty. The goal of the model is to optimize risk and return based on a portfolio wide risk exposure and therefore control and mitigate the downside risk such processes inevitably entail.*

## 1. OVERVIEW

Portfolio analysis is a technique that is used extensively in the financial world to analyze the benefits of diversification of assets. It is a process that is often referred to as the insurance principle, due to the reduction in risk achieved through the diversification of writing many policies against independent sources of risk (Bodie, 1993). Although the concept is now connected to finance theory, the idea of diversification is very old. The connection with finance theory actually dates to the Nobel Prize winning work on the efficient frontier of risk for assets published in 1952 by Harry Markowitz. The primary idea is that diversification of assets or projects can provide the same level of expected return with less variance than the same investment in a single asset or project. These same general techniques can be used to determine an optimum project portfolio given the risk tolerance of the organization in question (Cramer, et al., 2003).

Business growth that generates positive cash flows is generally driven by successful innovation, either from within the firm via R&D or through the acquisition of assets whose potential has been unrealized, with the former providing the greatest potential for large scale growth. And while real options analysis has been used to prioritize large projects (Schwartz, 2003) in some organizations and many of the principles behind it have a similar basis to those presented in this paper, it does not provide information useful for the diversification of risk across a portfolio of projects. Such risks can be considerable, and given the future stakes for the firm some questions to consider include:

- What can go wrong?

- Is it best to have a few large R&D projects?
- Or is it best to have several small to intermediate R&D projects?
- What is the optimal mix of R&D project types?
- How certain are the expected future cash flows from R&D projects?

In order to perform an analysis on a portfolio of projects, it is necessary to first assess the risk for the projects individually, then to determine the correlation of risk between the various projects. With that information in hand, standard financial formulas can be used to calculate the expected return and variance of the portfolio. This information in turn can be used to optimize the project portfolio so as to make the best use of scarce resources. This paper presents a methodology for both quantitatively assessing the risks of R&D projects using established project risk methodology and to estimate the correlation coefficients for a portfolio of R&D projects. The following three elements will be covered in detail:

- R&D Project Risk Assessment
- Estimation of Correlation Coefficients
- Analysis of a Sample Portfolio

The first two elements deal with the inputs to the portfolio analysis, with the last element providing a brief analysis of a sample R&D project portfolio. These elements will be followed by a conclusion. Financial theory will only be touched upon to the extent necessary to directly explain the calculations being performed. More detailed background can be retrieved if desired from any text book on investment.

## 2. R&D PROJECT RISK ASSESSMENT

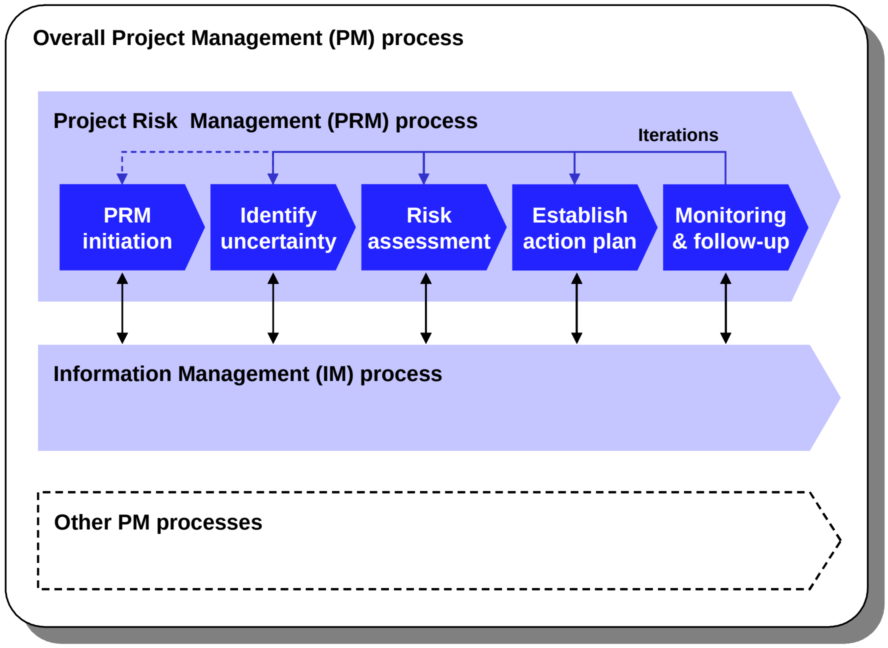
### 2.1 Introduction

The first problem to solve in order to analyze a portfolio of R&D projects is to find the expected return ($R_i$) and standard deviation ($\sigma_i$) for each project. A variety of means exist to make this calculation, but for this paper one will be briefly examined, with variations in analytical detail for a portfolio of smaller projects and for large projects. Overall, the idea is that for larger value projects that utilize more resources, a greater level of detail and effort should be expended in the assessment.

### 2.2 Methodology

Project risk management is a systematic approach of analyzing and managing threats and opportunities associated with a specific project, with project risk assessment as a subset of the overall approach. It is used to identify, assess, and rank the risks that may affect project objectives such as cost, schedule, and quality. This paper will focus on return, which is driven by all three, and the standard deviation (square root of the variance) of the return, which is the most basic measure of the risk of a project. In general the overall process of project risk management involves a five-step approach as illustrated in Figure 1, of which project risk assessment is a part.

**Figure 1 – Project Risk Management Process**




Of the steps outlined in the process, the two that are of importance for the purposes of this paper are the second and third items in the chain, those being the identification of uncertainties and the assessment of risk. Taken together, those two steps make up the project risk assessment portion of the overall project management process.

### *Identify Uncertainty*

This step is different depending on the size and complexity of the R&D Project to be assessed. In general, R&D projects will tend to have a series of possible outcomes, with each outcome having a particular value in terms of return. Each of the outcomes will also have some uncertainty associated with them. The end goal of this step is to identify the potential outcomes for a project with their associated probabilities, and then for each outcome assess the range of values that are deemed possible for that outcome.

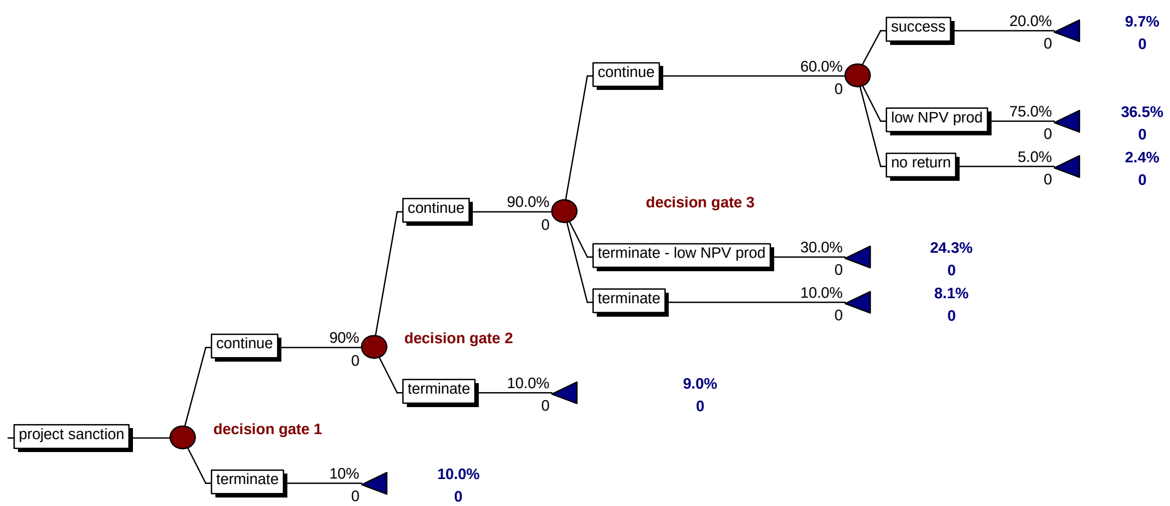
It is useful to think of an R&D project as a series of steps that go through decision gates. Decision gates are points at which sufficient new information has been developed to determine whether it is worthwhile to continue funding the project, or if it is necessary to terminate the project, either with no return (but more limited exposure in terms of expenditure) or with a more limited outcome than originally anticipated (Dixit and Pindyck, 1994). Unfortunately, it is not always the case that firms utilize the available decision gates, resulting in larger losses than necessary. This is often due to a lack of awareness, although it can also be that once projects are sanctioned within a given firm they survive until they are completed, for any number of reasons. For the purposes of this paper, a fundamental assumption is that if these techniques are being used, then firms will actually follow the decision gate process on their R&D projects, with the result being that large projects that get past the final gate will have a high probability of generating a positive return.

For smaller projects, the researcher or manager can simply go through a checklist of potential outcomes with some guidance on the assignment of values to those outcomes. It is unlikely that a small R&D project would have more than one decision gate (if any at all) after the initial project sanction. In the case of a large R&D project, it can be more useful to hold a workshop session for uncertainty identification, not dissimilar to the process used for the identification of major hazards. These projects would typically contain multiple decision gates where the project could be either terminated with no return or terminated with an outcome that generates a small return. Larger projects also present the possibility of benefits being derived even if the project is terminated early. Hence the value of holding a workshop session, usually for one day, and getting together the researcher(s) and relevant R&D managers, along with representatives from marketing, engineering, operations, finance, and any others with valid input. In all cases, the end result of the analysis will be a decision tree.

***Risk Assessment***

The first step to analyzing the uncertainty input is to determine probabilities of various outcomes occurring and to assign value ranges (in terms of NPV) to those outcomes. Given that researchers and marketers, much like engineering project staff, tend to be very optimistic about the chances for their project's success, some guidelines need to be used in this process. Probability of outcomes should be based on the historic results of the firm wherever possible. Therefore, if the firm generally sees no success at all from 30% of its research projects, then at least 30% of the total outcomes should go to failure. The NPV of each of those is dependent upon how far into the project the outcome is reached. Likewise, if only 10% of projects produce the originally desired product, then that should be the maximum outcome probability for an outcome of complete success. Once again, this outcome will still have a range of NPVs that need to be assigned. A very simple example of a decision tree produced using Precision Tree® software is provided in figure 2 as shown.

**Figure 2 – Example Decision Tree**




Assignment of project return ranges is based on the amount of expenditure and the discounted future cash flows (Eriksen, et al., 2003). For each outcome, an estimate for the most likely expenditure and future cash flows along with estimates for the high and low end are necessary.

A distribution, usually triangular, can then be assigned. This information can then be run through a standard Monte Carlo simulator (e.g., @RISK or Crystal Ball®) in order to calculate the mean cost and discounted cash flows for the project, along with their standard deviations. From that information, a standard NPV model can be used to calculate the expected return ($R_i$) and standard deviation ($\sigma_i$) for the project.

# 3. ESTIMATION OF CORRELATION COEFFICIENTS

## 3.1 Introduction

As with financial analysis, one of the more daunting tasks is to estimate the covariances between various projects. Covariance is simply the standard deviations of two projects multiplied by the correlation coefficient ($\rho$) between those projects, as shown below.

$$Cov(R_A,R_B) = \rho_{AB}\sigma_A\sigma_B$$

The correlation coefficient has a value of between 1 and -1, with a value of 1 equating to projects that are perfectly correlated and a value of -1 equating to projects whose risks are perfectly hedged. A downside to this method is that for a portfolio of projects, a total of $(n^2-n)/2$ estimates for *n* projects is required to estimate the variance of the portfolio (Bodie, 2003). The result is that for a portfolio of 10 projects, a total of 45 covariances, and hence correlation coefficients, need to be estimated. Therefore, it is very useful to limit the number of projects being analyzed by grouping any projects below a certain size threshold into one or two groupings, using a set of typical outcomes to represent those groups.

## 3.2 Estimation Technique

When looking at R&D projects, it is useful to realize that there is unlikely to be any hedging of risks (i.e., negative correlation coefficients) between such projects, so the values for the correlation coefficient will be most likely between 0 and 1. Some useful information for the use of guidelines when comparing projects is whether those projects are an effort to develop an entirely new product line, an attempt to improve an existing product line, or aimed at modification of an existing product line for use in a new market. Each of those situations then has its own set of circumstances, for instance in the case of developing a new product line, is it in a new or existing technology and is it in a new or existing market for the firm. Two R&D projects seeking to develop new product lines for existing markets will have a relatively high degree of correlation, whereas two R&D projects looking to develop new product lines with one in an existing market and one in a new market will have a lesser degree of correlation. In all cases it is important to consider that the correlation coefficients are based on the specific staff and culture within the given firm; in other words similar types of projects will tend to have similar degrees of success regardless of whether they are related. These factors can be built into the matrix format shown in Table 1 with suggested correlation coefficients.

**Table 1 – Sample Correlation Coefficients**

| | New Product, Market and Technology | New Product and Technology | New Product and Market | New Product | Product Modification for New Market | Product Improvement |
|---|---|---|---|---|---|---|
| **New Product, Market and Technology** | 0.8 | 0.8 | 0.7 | 0.5 | 0.3 | 0.1 |
| **New Product and Technology** | 0.8 | 0.8 | 0.3 | 0.7 | 0.3 | 0.2 |
| **New Product and Market** | 0.7 | 0.3 | 0.8 | 0.7 | 0.7 | 0.2 |
| **New Product** | 0.5 | 0.7 | 0.7 | 0.8 | 0.5 | 0.3 |
| **Product Modification for New Market** | 0.3 | 0.3 | 0.7 | 0.5 | 0.8 | 0.5 |
| **Product Improvement** | 0.1 | 0.2 | 0.2 | 0.3 | 0.5 | 0.8 |

Within table 1 the definitions for the project categories are that new refers to developing a new product or product line, developing a new basic technology platform, or entering a new market, and all combinations therein, all of which involve significant risk with the risk increasing with the number of new areas being approached; product modification for new markets is self explanatory and tends to be of moderate to high risk; and, product improvement refers to incremental advances in an existing product or product line, which tends to be a low risk (and often lower return) venture. Where new market or new technology is not specified, the existing status is being maintained.

As shown, the suggested correlation coefficients are higher for two projects that have similar aims, and lower for two projects that are very dissimilar. So while two projects to develop new products within the existing markets and technological toolkit of the firm would be expected to have a relatively high correlation coefficient on the order of 0.8 or more, the correlation coefficient for the combination of the most complex type of project, developing a new product from a new technology for a new market, with the most basic type of project, improving an existing product, would be expected to be much lower, on the order of 0.1. These values will of course vary depending on the specific circumstances of each firm. It is recommended that such a matrix of correlation coefficients be developed specifically for use in such analyses if sufficient historical data has been kept on the performance of R&D projects.

## 4. ANALYSIS OF A SAMPLE PORTFOLIO

Given the methodology laid out for estimating returns and variances on projects and for estimating the correlation coefficients between projects it is now possible to examine a sample portfolio of three R&D projects, with the purpose of demonstrating how diversification can help provide improved returns with less risk than can individual projects. The formulations for calculating return and variance on the portfolio are as follows:

$$R_P = w_A R_A + w_B R_B + w_C R_C$$

**The expected return ($R_P$) for the portfolio is the weighted (by value) average of the returns on the individual projects.**

$$\sigma_P^2 = w_A^2 \sigma_A^2 + w_B^2\, \sigma_B^2 + w_C^2\, \sigma_C^2 + 2 w_A w_B \rho_{AB} \sigma_A \sigma_B + 2 w_B w_C \rho_{BC} \sigma_B \sigma_C + 2 w_A w_C \rho_{AC} \sigma_A \sigma_C$$

**The variance ($\sigma_P^2$) for the portfolio is the weighted sum of the covariances between the projects.**

The example portfolio of R&D projects includes Project A, which is the introduction of a new product using a new technology platform. Project B is the improvement of an existing product. And Project C is the modification of an existing product to address the needs of a different market. Table 2 contains the returns, standard deviations, weightings by value, and correlation coefficients. The values for the returns and standard deviations are calculated using the methodology described in section 2. Weightings by value are based on the mean investment calculated for each project. Correlation coefficients have been taken from the sampling displayed in table 1, based on the project descriptions provided earlier.

**Table 2 – Example Portfolio**

| | **Project A** | **Project B** | **Project C** |
|---|---|---|---|
| $R_i$ | 30% | 12% | 20% |
| $\sigma_i$ | 25% | 4% | 14% |
| $w_i$ | 0.40 | 0.25 | 0.35 |
| | | | |
| $\rho_{AB}$ | 0.2 | | |
| $\rho_{BC}$ | 0.5 | | |
| $\rho_{AC}$ | 0.3 | | |

This small portfolio only provides a slight degree of diversification, as evidenced by the results displayed below:

$R_P$ = 22.0%
$\sigma_P$ = 12.8%

But even with this limited diversification, the combination of return and standard deviation is better than any of the projects individually (Wagner and Lau, 1971). Another way of viewing this is to look at the three projects again, this time giving them the same expected returns and standard deviations. Table 3 displays this revision.

**Table 3 – Revised Example Portfolio**

| | **Project A** | **Project B** | **Project C** |
|---|---|---|---|
| $R_i$ | 30% | 30% | 30% |
| $\sigma_i$ | 25% | 25% | 25% |
| $w_i$ | 0.40 | 0.25 | 0.35 |
| | | | |
| $\rho_{AB}$ | 0.2 | | |
| $\rho_{BC}$ | 0.5 | | |
| $\rho_{AC}$ | 0.3 | | |

This time the impact of diversification is much more evident, as seen in the results displayed below:

$R_P = 30.0\%$
$\sigma_P = 18.6\%$

By revising the sample portfolio of R&D projects so that they have the same expected returns and standard deviations, the value of diversification can be seen as reducing the standard deviation of the return from 25% to 18.6% while keeping the same expected return; an effect that will increase as the number of projects increases. Using the insurance principle, as the portfolio gets larger it will display progressively less variance, until the portfolio is diversified to the point where a residual variance remains which cannot be further reduced (Wagner and Lau, 1971). That residual variance will be approximately equivalent to the firm specific variance – in other words, one cannot construct a portfolio within a firm that is less risky than the firm itself.

## 5. SUMMARY AND CONCLUSION

Business growth is driven by many factors, but for many high margin businesses R&D projects are the primary means of achieving growth. Failure of the R&D function to produce results can force a firm to spend valuable cash to purchase what it was unable to develop, and in the worst cases can mean the end of the firm. It therefore becomes imperative for most firms that they actively manage the risk exposure from their portfolio of R&D projects.

Methods have been developed to analyze R&D projects and their risks, however little has been done with regard to diversifying those risks across a portfolio. The methods describe herein provide for the assessment of risks for individual R&D projects and to use the results of those assessments to perform analysis on the portfolio of projects with the intent of finding an optimal balance of risk and return for a finite amount of available investment. The fundamental lesson is that diversification can lead to outcomes that involve similar returns to individual projects, but with considerably less risk in that outcome. Further work is being performed to examine the extension of the index model to the analysis of portfolios of projects within a firm, including not just R&D projects, but also major capital projects and any other major projects such as mergers and acquisitions.

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