A Portfolio Approach to Capital Project Management

by

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SYNOPSIS

Title:	A portfolio approach to capital project management
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The proposition of this dissertation is that superior capital budgeting solutions can be attained by not only analyzing projects individually but rather as part of a portfolio of projects that has the objective of maximizing the company's range of multiple objectives, not only the economic benefit.

The dissertation starts with a detailed study of current techniques and an assessment of flaws and shortcomings. This study concludes with the requirements that any new approach or model must address in order to improve on the current practices. Based on these requirements, a new model is developed based on the portfolio approach that integrates all the assumptions, constraints, project and variable interrelationships. An important feature of the model is that it selects its portfolio of capital projects in such a way that it optimizes support for the company's multiple objectives, not only the economic objective. The dissertation concludes with the application of this model to a hypothetical case.

It is concluded that, by developing and using this model, a company can improve the analysis required before capital budgets are finalized.

KEY WORDS

Capital budgeting

Capital projects

Decision criteria

Monte Carlo simulation

Multiple objectives

Objective function

Optimization

Portfolio management

Portfolio of projects

Portfolio risk

Portfolio theory

Project risk

Project selection

Risk analysis

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PROBLEM STATEMENT AND OBJECTIVE

"The engineer's primary tasks include planning for the acquisition of equipment, designing, and producing products economically. The process of determining exactly which assets to invest in and how much to invest have a great deal of impact on the organization's 'bottom line' - the profitability. Sound engineering economic decisions, considering both time and risk, are key to the success of any organization."
- Chan S Park

1.1 Problem statement

Companies establish their infrastructure, plant, equipment and property through the capital projects that they select to implement. It is through the process of capital budgeting that companies select the specific projects. It is during this process where the important and far-reaching decisions are made regarding the commencement, postponement, downscaling, upsizing or even termination of capital projects. Whereas there are often many opportunities available, the company's own capabilities and capacities, be it physical, financial or technological are usually limited and it is therefore not possible to undertake all of the viable projects.

Capital projects require huge amounts of capital that is usually tied up for years. In order to take the best possible decisions, decision-makers usually perform detailed investigations and analyses regarding all the choices that are available to them. There are numerous techniques and tools available that the decision-maker can use to analyze various aspects of capital projects. Such investigations and analyses usually include the following aspects:

- It is important to decide on the *decision criterion* to be used in the comparison of the different projects. The *decision criterion* is calculated for each of the projects and is then used in the project comparisons of the decision-making process.

- The next important aspect is the choice of a *risk analysis technique*. In practice most companies simply base their decisions on the decision criteria, which are normally based on a best-estimate or expected value approach. For many decision situations such an approach will suffice, but it often happens that the projects are of such significance and impact, that a further level of investigation is justifiable in order to identify the effect of the inherent risks and uncertainties for the different projects. It is for this purpose that a risk analysis technique is applied.
- Once all the investigation work has been completed on the different projects, including the existing projects, and one has identified all the viable projects, it is still necessary to make the selection of the best possible combination of projects given the limitations on the company's resources and capabilities. It is therefore necessary to decide on which is the most appropriate *selection technique.*

When considering these different aspects of the problem, one can logically categorize the current techniques under the three headings as shown in Table 1.

Decision criteria	Risk analysis	Selection techniques
• Payback Period • Discounted Payback Period • Accounting rate of return • Internal rate of return • Net Present Value	• Risk-adjusted discount rate • Certainty equivalent method • Sensitivity analysis • Break-even analysis • Monte Carlo simulation	• Ranking • Linear programming • Integer programming • Mixed programming tools • Analytical hierarchy process

<u>Table 1:</u> Current capital project techniques

It is the author's opinion that the following problem areas with the way in which the capital budgeting process is applied, can lead to poor decisions:

- The capital budgeting process is often based on only one or two of the techniques in Table 1. Risk analysis is frequently left out because of the additional effort and the view that the level of the uncertainties will lead to spurious and inconclusive results.
- The aspects and the techniques described above are frequently addressed in isolation of each other. In other words, the above three aspects are often seen as three separate exercises.
- Companies still use techniques that have serious flaws and shortcomings.
- When working through the capital budgeting process, companies often examine only the new projects that are under consideration without re-assessing the viability of existing projects. This could be because of various reasons such as the difficulty of tracking the actual progress of a project, the general perception that capital projects are irreversible, company politics, personal egos that can be involved or the fact that the environment is changing so quickly.

It must be recognized that the final decisions in capital budgeting do not solely rely on the results of the various techniques. Management's experience and subjective 'gut-feel' certainly plays a very important role. However, the whole process will be much more efficient if the quality and reliability of the findings of the investigations and analyses can be improved.

1.2 Objective of the dissertation

The objective of this dissertation is to develop a model that will address the current problems with the capital budgeting process through an approach that integrates and optimizes the analysis, selection and the continued management of a company's existing and new capital projects.

In order to achieve this objective in this dissertation, the following approach was followed:

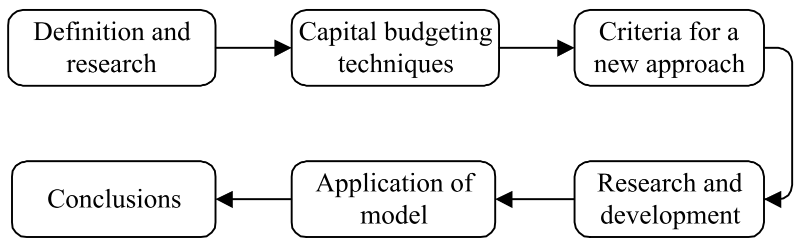


Figure 1: Approach followed for the dissertation.

Definition and research

The first step in the approach is to define and to study the nature of capital projects. It is imperative that there is a clear understanding of what capital projects are, what factors must be considered and what processes are followed in capital budgeting.

Capital budgeting techniques

The second step in the approach is to identify and to study the various techniques that are used in the assessment of capital projects. The objective is to create a clear understanding of the methods, the underlying assumptions, the use, the advantages and the disadvantages of each technique.

Criteria for a new approach

Given the thorough understanding obtained regarding the merits of the current techniques, the objective of this step is to formulate the requirements for an alternative approach. These requirements will form the yardstick against which the proposed model can be judged.

Research and development

The purpose of this step is to firstly identify and study all the detailed aspects involved in the process and also to gain a good understanding of any new concepts that could be applied in the new proposed model. The second objective is to apply this knowledge in the development of the new proposed model.

Application of model

Having developed the model in the previous step, the objective with this step will be to illustrate the use of the model with an application to a hypothetical case. Specific emphasis will be placed on showing how this model addresses the shortcomings of the current processes and techniques.

Conclusions

The objectives will be to summarize the main findings regarding the application of the model, to assess its merits, to indicate any shortcomings that still exist and to indicate areas requiring further investigation and development.

CAPITAL BUDGETING TECHNIQUES

The objective of this chapter is firstly to define and describe capital projects and the capital budgeting process, secondly to describe and to consider the merits of the main capital project budgeting techniques and lastly to conclude by formulating the requirements for an integrated approach to capital budgeting that will achieve and maintain the optimal selection of capital projects while also addressing the shortcomings of the current techniques and practices. Figure 2 illustrates the sections of the overall approach to the dissertation that are included in this chapter.

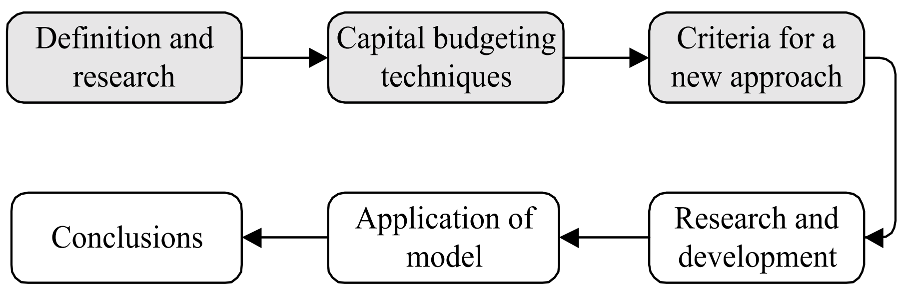


Figure 2: Chapter 2 objectives indicated by the shaded shapes.

2.1 Capital projects defined

2.1	Capital projects defined	***Capital projects defined*** The objectives of this section are: • To define capital projects. • To describe the importance of capital projects.
2.2	The capital budgeting process	
2.3	Decision criteria	
2.3	Risk analysis	
2.4	Selection techniques	
2.5	Conclusion	

A Capital Project can be defined as *"... any scheme which involves the investment of resources at the outset, in return for the expectation of a net benefit at a later stage ..."* [Levin *et al*, 1995]. It is through capital projects that companies establish their infrastructure, plant, equipment and property. The following examples illustrate the scope and magnitude of capital projects:

- The 2003 annual report of Sasol, the largest South African petrochemical company, states that the company has about 150 capital projects with a total value of about R60 billion in various stages of execution.
- In 1998 Vodacom, a South African mobile telephone company, entered into a contract to purchase $75 million of base-station equipment as part of a $489 million capital expenditure program in order to increase capacity and to remain competitive with its main rival, Mobile Telephone Networks. [Johnson H, 1999].
- Kumba Resources in South Africa is currently investigating the feasibility of the Faleme iron ore project in Senegal, where the total capital cost is currently estimated at $950m, which includes the capital for a mine and port handling facilities, a railway line and rolling stock and a new deepwater port. [Financial Mail, July 18 2004].
- UK-listed Kenmare Resources is currently busy finalizing the financing arrangements for the Moma Titanium Minerals Project in Mozambique. The

capital required for the mine is estimated at $220m. The mine plan was done for 20 years, even though the resource life greatly exceeds this. [Financial Mail, July 18 2004; www.kenmareresources.com/projects]

Generally capital projects share the following characteristics:

i) Huge sums of capital are involved.

ii) The decisions about capital projects form an integral part of a company's strategic management.

iii) Capital Projects require a long-term commitment of capital.

iv) Due to the scope and size, such projects are often irreversible.

v) The projects are long-term in nature, as returns normally realize over a number of years in the future.

vi) There is always a significant level of risk and uncertainty involved in predicting the future returns.

Capital projects can be categorized as in Table 2. [Brealy *et al,* 1996]:

CATEGORY	DESCRIPTION
Compulsory Outlays	• Adherence to Safety Regulations • Environmental Controls (e.g. pollution control equipment) • Compliance to new legal requirements • Social Responsibility Outlays
Maintenance or Cost Reduction	• Machine replacement • Process improvements • New Technology
Capacity Expansion in Existing Business	• Upgrading of existing assets • Creating additional capacity • Take-overs
New Products or Ventures	• Research and Development • New business ventures • New Product Development

<u>Table 2:</u> Typical capital project categories

The importance of capital projects is clear, given their nature and the following considerations [Du Toit *et al*, 1997]:

i) Given the large amounts of funding required, poor decisions could result in large unexpected losses.

ii) Capital Projects require a long-term commitment of capital and since such projects are to a large extent irreversible, poor decisions can lead to substantial losses but will also prevent a company from pursuing other more attractive opportunities, thereby threatening the company's future.

iii) As such projects influence its long-term viability, the company's market value is very sensitive to the Capital Project decisions taken by the company.

On a higher level, one can certainly say that the strength of a nation's economy depends to a large extent on the collective outcomes of all the capital projects undertaken by the various companies and by its government departments.

2.2 The capital budgeting process

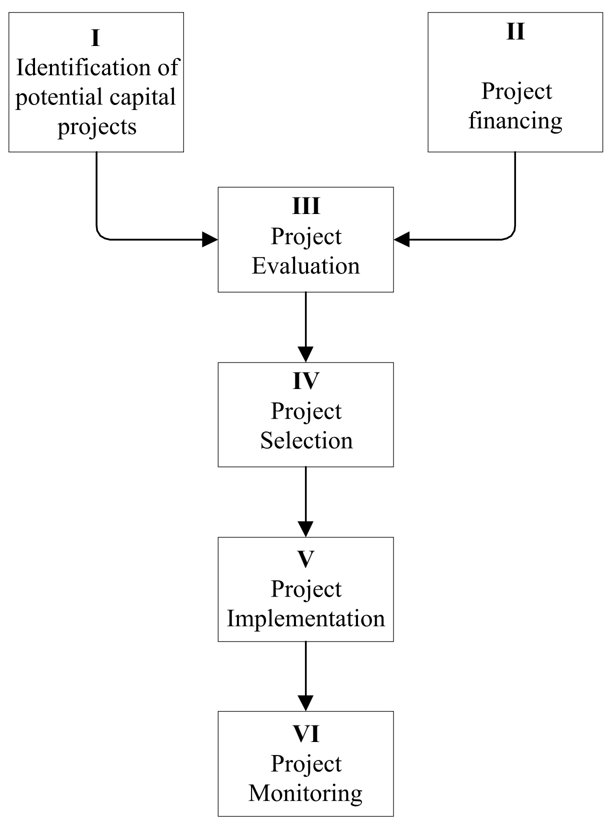
2.1	Capital projects defined
2.2	The capital budgeting process
2.3	Decision criteria
2.4	Risk analysis
2.5	Selection techniques
2.6	Conclusion

The capital budgeting process

The objectives of this section are:

- To describe the typical capital budgeting process.
- To indicate where the capital budgeting techniques are applied and where difficulties arise.

Figure 3 shows the general process that most companies follow when drawing up their capital budgets. Each step in the process is then described in more detail.



<u>Figure 3:</u> The Capital Budgeting Process

Identification of potential Capital Projects

New capital projects can be seen as the fuel that a company needs to grow and to increase the value to its shareholders. Companies therefore spend a great deal of time and effort to identify and to develop those opportunities that will contribute most to the attainment of its long-term strategic goals and plans. Such ideas originate both from within and from outside and companies have various incentive schemes in place to encourage its own staff to submit new and innovative proposals. In many companies this identification process is documented in detailed procedure manuals. This process often involves the identification and comparison of alternatives that will solve a specific problem or that will achieve a certain objective.

Project Financing

The company needs to decide on the sources of finance for its capital projects and how much to obtain from each source. This is necessary in order to know what the cost of the financing is. It is important to make a clear distinction between the following two basic questions [Brealy, et al (1996)]:

- *What real assets should the company invest in?*
- *How should the cash for the investment be raised?*

The answer to the first question is the company's **capital budgeting decision** and the answer to the second question is the **financing decision**.

Project Evaluation

A project is evaluated in terms of the following criteria:

i) The extent to which the project supports and is aligned with the company's strategy.

ii) Can the company cater for and handle the technical requirements of the project?

iii) The timing of the project should be in line with the company's long-range plans. If not, the project should be kept for later consideration, when circumstances are different and when the timing may be right.

iv) The project must exceed the company's minimum acceptable financial standards. Most of the techniques used in determining the financial merit of a project are presented later in this chapter under paragraphs 2.2 and 2.3. Note that "financial standards" can reflect both financial returns and the risk inherent in the project.

Project Selection

Due to constraints such as limited capital availability and other physical capacities of plant, equipment and staff, it is not always possible to continue with all the projects that might have passed the evaluation phase. It is during this phase that it is necessary to select that combination of projects that best suits the company's strategy and long-range plans and that the company is able to implement and manage given all the relevant constraints and the company's capabilities. The techniques that can be used in this selection process are presented later in this chapter under paragraph 2.4.

Project Implementation

The approval of the capital budget for a project often does not mean that the go-ahead has been given. Many companies require a formal appropriation request accompanied by more backup information, before the authorization for a project is given. Once the project commences, it is critical that all activities are properly integrated and managed so that the project deliverables adhere to the required quality standards and so that the expenditure can be kept within the budget.

Project Monitoring

Once a project has started, an on-going monitoring process must also commence so that the actual and planned results can be compared. Such monitoring through techniques such as project management, continues throughout the project's entire life. Future decisions about the project depend on the information gathered during this monitoring process.

2.3 Decision Criteria

2.1	Capital projects defined	***Decision Criteria*** The objectives of this section are: • To present the decision criteria that companies use to make investment decisions. • To discuss the usage of the criteria. • To identify the advantages and the disadvantages of the decision criteria.
2.2	The capital budgeting process	
2.3	Decision criteria	
2.4	Risk analysis	
2.5	Selection techniques	
2.6	Conclusion	

The *decision criteria* in capital budgeting are calculated measures that one can use to compare the cash flows of different projects or alternatives. An important component of the model developed in this dissertation is the decision criterion. Before one is selected it is important to have a clear understanding of the decision criteria currently available. The following decision criteria are examined in this section:

- Payback period.
- Discounted payback period.
- Accounting rate of return.
- Internal rate of return.
- Net present value.

In order to illustrate the application of these techniques, the Electric Scooter Project (from [Brealy et al (1996)]) will be used as an example. Table 3 presents the assumptions and projected cash flows of the project.

Assumptions	
Investment =	150,000,000
Fixed costs =	30,000,000
Variable costs per unit =	3,000
Annual Sales =	100,000
Price =	3,750
Tax rate =	50%
Discount rate =	10%

	Year										
	0	1	2	3	4	5	6	7	8	9	10
1. Sales Volume (000's)		100	100	100	100	100	100	100	100	100	100
2. Revenue (Rm)		375	375	375	375	375	375	375	375	375	375
3. Investment (Rm)	-150										
4. Fixed Costs (Rm)		-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
5. Variable Costs (Rm)		-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
6. Depreciation (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
7. Pre-tax profit (Rm)		30	30	30	30	30	30	30	30	30	30
8. Tax (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
9. Net Cash Flow (Rm) [2-4-5-8]	-150	30	30	30	30	30	30	30	30	30	30

Table 3: The assumptions and the projected cash flows for the Electric Scooter Project.

The Electric Scooter project's cash flows consist of the following components:

- A 10 year projection period.
- An initial investment amount of R150m.
- Straight-line depreciation of the initial investment over the 10 years with no salvage value.
- Annual fixed costs of R30m.
- Variable manufacturing cost of R3,000 per unit.
- Annual sales forecast of 100,000 units.
- Price of R3,750 per unit.
- Effective tax rate of 50%.

2.3.1 Payback Period

[Johnson H (1999)] defines the *payback period* as the expected length of time for aggregate positive cash flows to equal the initial cost, or the time it is expected to take to recover the initial investment. In order to use the technique as a criterion, a *cutoff period* is specified and all those projects with payback periods shorter than the cutoff period are then acceptable whereas all those with payback periods longer than the cutoff period are not acceptable.

Table 4 illustrates the calculation of the payback period for the Electric Scooter Project.

Year	Net Cash Flow (Rm)	Aggregate Cash Flows	
0	-150	-150	
1	30	-120	
2	30	-90	
3	30	-60	
4	30	-30	
5	30	0	….. **Payback Period = 5 years**
6	30	30	
7	30	60	
8	30	90	
9	30	120	
10	30	150	

<u>Table 4:</u> Determination of payback period for the Electric Scooter project.

In this project it takes 5 years for the positive cash flows to equal the initial cost, hence the payback period of 5 years. If the company's cutoff period is shorter than 5 years, then this project will be rejected and vice versa.

[Yee-Ching (2004)] found that over half of the Canadian Municipal Governments that use capital budgeting techniques use the payback period as the primary criterion. In a survey amongst smaller companies [Block (1999)] found that the payback period was preferred by nearly 43% of the companies. A survey amongst the Fortune 500 companies [Burns R.M. et al (1987)] showed that payback period was not the preferred technique.

Advantages of Payback Period

i) Its simplicity is an advantage, as it is easy to understand and to explain.

ii) It gives an indication of how long the initial investment will be "at risk" and is therefore an indication of the risk involved in the projects.

Shortcomings of the Payback Period

i) The technique does not take all the cash flows into account, as it ignores those projected cash flows after the payback period.

ii) The technique ignores the time value of money in that cash flows that occur at different points in time are simply added and compared with the initial capital amount.

iii) Payback period does not give any indication of the contribution that a project will make to the value of the company.

iv) It is tricky to decide on an appropriate cutoff period. If the cutoff period is too long, it is possible to accept projects that will not be acceptable on a discounted cash flow basis. On the other hand, if the cutoff period is too short, one might reject projects that will however be acceptable on a discounted cash flow basis.

v) The payback period does not have the additivity property of some other techniques. In other words, the sum of the respective payback periods of different projects is not really useful. It is also not useful to calculate an average payback period, as it will attach equal importance to all the projects involved.

2.3.2 Discounted Payback Period

The discounted payback period is the expected length of time for aggregate positive discounted cash flows to equal the initial cost, or the time it is expected to take to recover the initial investment with the discounted values of the future cash flows. The calculation of the discounted payback period is similar to the calculation of the payback period, except that the cash flows are discounted before the payback period is calculated. Table 5 shows the calculation of the discounted payback period for the Electric Scooter Project.

Discount rate =		10%		
Year	**Net Cash Flow (Rm)**	**Discounted cash flow**	**Aggregate discounted cash flows**	
0	-150	-150.00	-150.00	
1	30	27.27	-122.73	
2	30	24.79	-97.93	
3	30	22.54	-75.39	
4	30	20.49	-54.90	
5	30	18.63	-36.28	
6	30	16.93	-19.34	
7	30	15.39	-3.95	7.28 years
8	30	14.00	10.05	
9	30	12.72	22.77	
10	30	11.57	34.34	

<u>Table 5:</u> Determination of the discounted payback period for the Electric Scooter Project.

Table 5 shows that the discounted payback period should be between 7 and 8 years. The answer of 7.28 years is found through linear interpolation with the aggregate discounted cash flow amounts. As with the payback period, the decision will depend on the company's cutoff period for the discounted payback period.

The discounted payback method certainly addresses the important shortcoming of the normal payback period of not taking the time value of money into account. However it still focuses only on the recovery of the initial cost and still ignores all the cash flows after the discounted payback period.

2.3.3 Accounting rate of return (ARR)

The Accounting rate of return (sometimes called the "book rate of the return") is based on the incremental effects of the project on the company's balance sheet. It is determined by dividing the average projected profits (after depreciation and taxes) over the life of the project by the average book value of the investment in the project. [Johnson H (1999)] provides the following formula for the Accounting rate of return:

$$ARR = \frac{\left(\dfrac{\sum_{t=1}^{n} (CF_t - Dep_t)}{n} \right)}{ABV}$$

where:

$ARR =$	Accounting rate of return.
$CF_t =$	Net cash flow in year t.
$Dep_t =$	Depreciation expense in year t.
$n =$	Expected number of years of project life.
$ABV =$	Average book value of the project.

Table 6 shows how the ARR is determined for the Electric Scooter Project. The first step is to determine the income by deducting the depreciation charge from the net after-tax cash flow. Next, one has to determine the book value for every year by deducting the accumulated depreciation from the initial investment amount. The ARR is calculated by dividing the average income by the average book value.

	Year										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Net Cash Flow (Rm)	-150	30	30	30	30	30	30	30	30	30	30
Depreciation (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Income (Rm)		15	15	15	15	15	15	15	15	15	15
Book Value (Rm)	150	135	120	105	90	75	60	45	30	15	-
Averages											
Income	15.00										
Book Value	82.50										
Accounting Rate of Return =	**18.2%**										

Table 6: Determination of the accounting rate of return for the Electric Scooter Project.

This decision criterion is then measured against the company's own book rate of return or against an external yardstick such as the average book rate of return for the industry that the company operates in. In the above example, the project will be rejected if this yardstick is higher than the project's 18.2%.

This criterion is not reliable as it ignores the timing of the cash flows and since it is based on accounting income and not on the project cash flows. Another problem lies in the way in which the criterion is used to make decisions, namely by comparing the measure to a yardstick that is based on the company's current profitability on its existing business.

2.3.4 Internal rate of return (IRR)

The *internal rate of return* (IRR) is a measure of the return generated by a project. The internal rate of return (IRR) is defined as that rate of discount that causes the present value of the projected future project cash flows to be exactly equal to the initial cost of the project.

The IRR is therefore the rate that will satisfy the following equation [Johnson H (1999)]:

$$I_0 = \sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t}$$

where:

I_0 = Initial project cost.
CF_t = Net cash flow in year t.
IRR = Internal rate of return.
n = Expected number of years of project life.

Table 7 shows the result of applying the above formula to the net cash flows of the Electric Scooter Project.

	Year										
	0	1	2	3	4	5	6	7	8	9	10
Net Cash Flow (Rm)	-150	30	30	30	30	30	30	30	30	30	30
Internal rate of return =	15.10%										

<u>Table 7:</u> Determination of the internal rate of return (IRR) for the Electric Scooter Project.

To use the IRR as a decision criterion, one has to compare the IRR to the company's *minimum attractive rate of return* (MARR). The IRR rule states that the company must not accept a project if its IRR is less than the company's MARR.

The MARR is often set equal to the *opportunity cost of capital*, which is defined as the rate of return offered by the other alternative comparative investments. Another approach is to set the MARR equal to the company's *cost of capital* plus a margin to allow for the specific risks inherent in the project. Since the risks differ from project to project, the risk margins and therefore the MARR's should also differ from project to project. In some cases companies also add a profit margin into the MARR in order to ensure that a minimum level of profit is at least generated by the projects. Once determined, the MARR becomes an important criterion or yardstick in the company's economy studies.

IRR is a very popular decision criterion. A survey amongst the Fortune 500 companies [Burns R.M. et al (1987)] showed that 84% of the companies use IRR as a decision criterion in capital budgeting.

Advantages of Internal Rate of Return

i) The IRR takes all the project cash flows into account. It therefore addresses the shortcoming of the payback methods where the projected cash flows after the payback period are ignored.

ii) The IRR takes the timing of the cash flows and therefore the time value of money into account.

Shortcomings of Internal Rate of Return

i) The IRR does not give an indication of when the initial investment has been recovered.

ii) The IRR does not give an indication of the actual value that a project can add to the company.

iii) It is often difficult for companies to decide on an appropriate MARR. One reason for this is that it might be difficult to find the alternative comparative investment whose return can be set as the opportunity cost of capital, which is then used as the MARR.

iv) Another complexity is that the MARR should theoretically vary from project to project in order to reflect the differences in risk (the higher the risk, the higher the MARR).

v) Implicit in the way that the IRR is determined, is the assumption that all cash flows are reinvested at a reinvestment rate equal to the IRR. When the IRR differs significantly from the company's true reinvestment opportunities, the IRR does not accurately reflect the true rate of return of the project in question. [Johnson H (1999)] shows how one can calculate an implied rate of return in such cases.

vi) For certain projects, one might find more than one IRR-value that will satisfy the equation. This happens when there are more than one sign change in the projected cash flows.

vii) The IRR-rule often lead to wrong decisions when one has to select the best combination of projects from several alternatives. [Brealy et al (1996)] illustrates this problem with a number of examples and concluded that the IRR-rule should not be used to rank projects when there is a capital constraint. The main reason for this is that the fact that the IRR-formula implies a reinvestment rate equal to the IRR. When the IRR is significantly higher that the company's cost of capital, reinvestment at that rate is unrealistic and wrong conclusions can be made.

viii) Similar to payback period, the IRR does not have the additivity property of summing or averaging the IRR's of a number of projects. If it is required to calculate the IRR of a selection of projects, it is better to sum the net cash flows of all the projects and to calculate the IRR of the aggregate cash flows.

Although IRR has shortcomings that one should be aware of, it is still a much better criterion than payback period and, when used properly, it gives the same answer as the more accepted Net Present Value criterion, which is discussed in the next section.

2.3.5 Net present value (NPV)

The net present value (NPV) criterion is widely accepted as the most reliable decision criterion to use for capital budgeting. The NPV is defined as the present value of all the present and future projected positive and negative cash flows, as indicated by the following formula [Johnson H (1999)]:

$$NPV = \left(\sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} \right) - I_0$$

where:

NPV = Net present value
CF_t = Net after-tax cash flow in year t.
k = Discount rate.
n = Expected number of years of project life.
I_0 = Initial project cost.

The discount rate, k, should equate the rate of return on the next best investment alternative of similar risk, also known as the opportunity cost of capital or the minimum attractive rate of return, MARR. Note that since the risk levels vary from project to project and since one must allow for the risk level in the discount rate, it happens that the discount rates can vary from project to project. See paragraph 2.4.1 for a discussion on how to adjust the discount rate for risk.

The NPV decision rule is to give further consideration to those projects whose NPV's are greater than zero. A positive NPV implies that the projected cash flows indicate a return in excess of the discount rate. Any project that provides returns in excess of the MARR certainly adds additional value to the company, thereby increasing shareholder wealth. Using a discount rate of 10%, Table 8 shows the calculation of the net present value of the Electric Scooter Project.

Assumptions	
Investment =	150,000,000
Fixed costs =	30,000,000
Variable costs per unit =	3,000
Annual Sales =	100,000
Price =	3,750
Tax rate =	50%
Discount rate =	10%

	Year										
	0	1	2	3	4	5	6	7	8	9	10
1. Sales Volume (000's)		100	100	100	100	100	100	100	100	100	100
2. Revenue (Rm)		375	375	375	375	375	375	375	375	375	375
3. Investment (Rm)	-150										
4. Fixed Costs (Rm)		-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
5. Variable Costs (Rm)		-300	-300	-300	-300	-300	-300	-300	-300	-300	-300
6. Depreciation (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
7. Pre-tax profit (Rm)		30	30	30	30	30	30	30	30	30	30
8. Tax (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
9. Net Cash Flow (Rm) [2-4-5-8]	-150	30	30	30	30	30	30	30	30	30	30

Net Present Value (Rm) = **31.22**

<u>Table 8:</u> Calculation of the net present value (NPV) of the Electric Scooter Project.

With a positive NPV of R31.22m, the project is definitely acceptable according to the NPV-rule.

Advantages of Net Present Value (NPV)

i) The NPV takes into account the timing of all the cash flows.

ii) The NPV is a measure (in present day terms) of the added value that a project is projected to make to the company value.

iii) One can easily compare the NPV's of different project, irrespective of whether the project lives and cash flow patterns are different.

iv) By adding their NPV's one can determine the added value of a selection of projects.

v) It is easy to determine the impact of a project as the NPV is expressed in present day terms.

Shortcomings of the net present value (NPV)

i) The implicit assumption in respect of the NPV [Du Toit GS et al (1997)] is that all cash flows generated by a project could be reinvested at the rate, *k* for the remainder of the project life. It might be that the opportunity cost of capital in the short term differs from the cost for longer terms. In such a scenario it is difficult to determine one fixed discount rate for the NPV calculation.

ii) Since the discount rate is equal to the rate of return on the next best investment alternative of similar risk, it implies that there is a risk margin included in the rate. By using such a discount rate, one therefore implies that all the cash flow components carry the same risk as reflected by the risk margin in the discount rate. There is however components of the cash flows (such as the *depreciation tax shield*, which will be covered in the next chapter) that can be considered as safe and that should therefore be discounted at a rate that does not include the said risk margin.

2.4 Risk analysis

2.1	Capital projects defined	***Risk analysis*** The objectives of this section are: • To present the risk analysis techniques that companies use in the analysis of capital projects. • To discuss the usage of the techniques. • To identify the advantages and the disadvantages of the risk analysis techniques.
2.2	The capital budgeting process	
2.3	Decision criteria	
2.4	Risk analysis	
2.5	Selection techniques	
2.6	Conclusion	

Given the impact of capital projects on a company's long-term viability, it is important for companies to understand why projects could fail. The calculation of a decision criterion based on best-estimate predicted cash flows is therefore not sufficient, as it does not indicate the level and nature of the project risks. Hence the need for a better understanding of what can go wrong and what the impact would be on the project outcome. A number of risk analysis techniques have been developed for this purpose and this section will describe the following techniques:

- Risk-adjusted discount rate
- Certainty equivalent method
- Sensitivity analysis
- Break-even analysis
- Monte Carlo simulation

2.4.1 Risk-adjusted discount rate

In the explanation of the net present value (NPV) method (see paragraph 2.3.5) it was stated that the discount rate should equate the rate of return on the next best investment alternative *of similar risk*. The premise of the risk-adjusted discount rate is that discount rate should be directly proportional to the risk. The discount rate for risky projects must therefore be higher than the discount rate for projects with lower risks.

Where the risk of a project is equivalent to the average risk of the company, one can use the company's cost of capital as the discount rate in the calculation of the project's NPV. However when the project's risk differs from the company's risk, further adjustments are required. [Du Toit *et al* (1997)] suggest the following formula for the risk-adjusted discount rate:

$$k = i + u + a$$

where:

k = The risk-adjusted discount rate.
i = The risk-free rate.
u = An adjustment for the normal risk of the company.
a = An adjustment for the risk associated with the specific project. If the project has more risk that the company, ***a*** will be positive and vice versa.

Although many companies select and use some individual discount rate, many apply the above principle by having different discount rates for different categories of investment. [Brealy *et al* (1996)] provides the following as an example:

Category	Discount rate
Speculative ventures	30%
New products	20%
Expansion of existing business	15% (company cost of capital)
Cost improvement, known technology	10%

<u>Table 9:</u> Examples of risk-adjusted discount rates for different risk-based project categories.

Once a company has decided on a risk-adjusted discount rate, the NPV for the project is calculated using this discount rate. The same NPV decision rule applies whereby the company can accept those projects whose NPV's are equal to or greater than zero.

Advantages of the risk-adjusted discount rate as a way of dealing with risk:

i) Due to its relative simplicity it is widely used.

ii) It accounts for project risk by requiring a higher return from the risky projects.

Shortcomings of the risk-adjusted discount rate as way of dealing with risk:

i) It is difficult to determine the correct risk margin for a specific project.

ii) The use of the risk-adjusted discount rate attaches the same risk margin to each cash flow and its components. There is however components of the cash flows (such as the *depreciation tax shield*, which will be covered in the next chapter) that can be considered as safe and that should therefore be discounted at a rate that does not include the said risk margin.

iii) By attaching the same risk margin to each cash flow, irrespective of its timing, the risk-adjusted discount rate ignores the fact that uncertainty increases over time and that the risk margin should therefore also increase the further the cash flow is projected into the future.

2.4.2 Certainty equivalent method

According to the certainty equivalent method, a net present value (NPV) is also calculated. However, instead of adjusting the discount rate (as was done with the risk-adjusted discount rate in paragraph 2.4.1) the risk in the project is accounted for by making adjustments to the project cash flows, which are then discounted at a risk-free discount rate in order to get the NPV. [Du Toit *et al* (1997)] defines this adjustment as follows:
"The certainty equivalent of a risky cash flow is defined as that part of the cash flow that the decision-maker would be prepared to accept with certainty in stead of the total risky cash flow."

By applying this approach the certainty equivalent net present value can be calculated by using the following formula [Du Toit *et al* (1997)]:

$$CE(NPV) = -I_0 \times CEC_0 + \sum_{t=1}^{n} \frac{CEC_t \times CF_t}{\left(1 + r_f\right)^t}$$

where:

$CE(NPV)$ = The certainty equivalent net present value.
I_0 = The initial investment amount.
CEC_t = The certainty equivalent coefficient (any value between 0 and 1) of the cash flow in period t, where $t = 0, 1, 2, \ldots, n$.
CF_t = The projected net project cash flow in period t.
r_f = Risk-free discount rate.

Advantages of the certainty equivalent method as a way of dealing with risk:

i) It allows the decision-maker to more accurately reflect the risk in each cash flow.

ii) It allows the decision-maker to account for the fact that risk and uncertainty increase the further one projects into the future.

iii) It allows the decision-maker to reflect the company's attitude towards the risk.

Shortcoming of the certainty equivalent method as way of dealing with risk:

Even if one has the probability distributions of the projected cash flows, it can still be difficult to determine the correct certainty equivalent coefficients.

2.4.3 Sensitivity analysis

Given all the risks and uncertainties that are part of capital projects, it is most unlikely that the decision-maker's best estimate of the decision criterion will be accurate. It will therefore be very helpful to know how sensitive the decision criterion will be to changes in the key variables. This is where sensitivity analysis can provide useful insight into the factors that can influence the eventual outcome of a project.

[Tarquin et al (1976)] suggested the following general procedure that should be followed when conducting a sensitivity analysis:

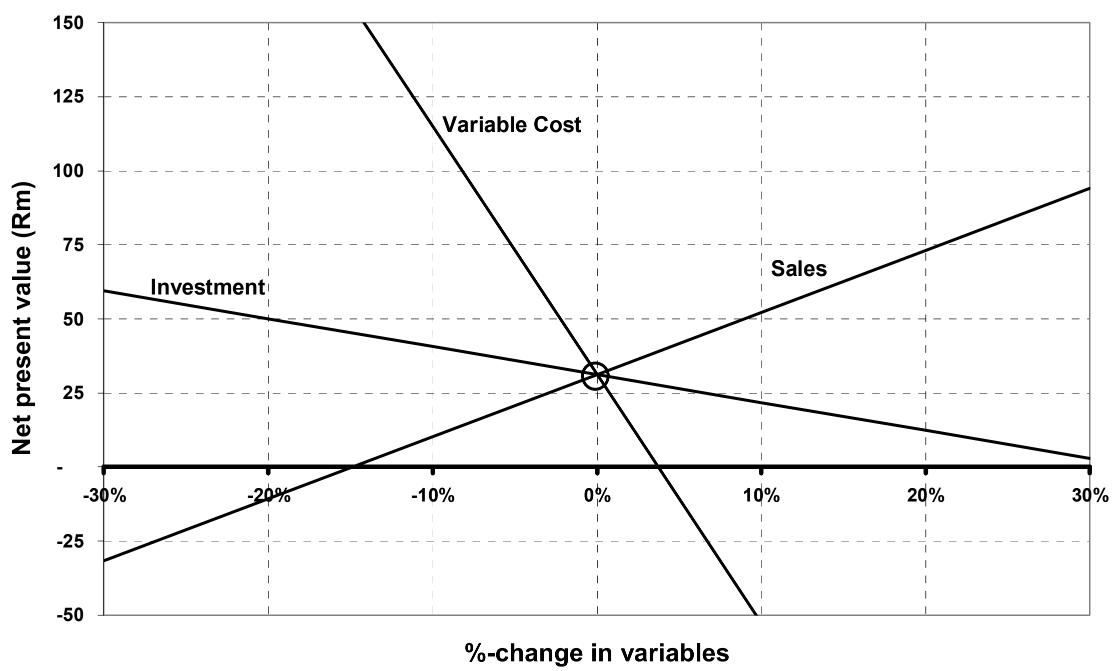
i) Determine the variables that are most likely to vary from the estimated value.

ii) Select the probable range and increment of variation for each variable.

iii) Compute and plot the value of the decision criterion resulting from changing the above variables within their probable ranges.

By examining the changes in the decision criterion resulting from the changes in the variables, the decision-maker will be able to identify those variables to which the decision criterion is most sensitive. Given this knowledge the decision-maker knows which are the variables to concentrate on in the projection and also in the management of the project, once it has commenced.

Figure 4 below shows the result of a sensitivity analysis that was done for the Electric Scooter project. The objective was to examine the sensitivity of the project's net present value (NPV) to changes in the initial investment, the variable manufacturing cost per unit and sales volume.



<u>Figure 4:</u> Sensitivity Analysis on the Electric Scooter project.

The horizontal axis of the graph indicates the %-change in the specific variable and the vertical axis shows the project's NPV. For example, from the graph, one can see that a 20%-drop in the initial investment will result in a NPV of about R50m, which is a 60% increase on the original NPV-amount. Similarly, one can see that a 20% increase in sales volume will result in a NPV of R73m, which is a 120% increase on the original NPV.

From Figure 4 it is clear that the NPV is most sensitive to changes in the variable cost per unit. By examining this variable further, the decision-maker will find that an increase of nearly 4% in the variable cost from R3,000 to R3,112 will result in a negative NPV. With this knowledge, the decision-maker can now assess what the likelihood of this is and this might lead to a re-consideration of whether to accept the project or not.

The method described above examines the sensitivities in the decision criterion as the variables are changes one at a time. It is important in this analysis to ensure that the model always accurately reflects any logical relationships between the variables so that the relationships between all the variables always remain logical.

Another approach to sensitivity analysis, is to examine the effect of different *scenarios* on the decision criterion. The decision-maker can describe say three scenarios, namely *pessimistic*, *realistic* and *optimistic*. By setting the key variables to the levels that will constitute the given scenarios, one can examine the sensitivity of the decision criterion to the different scenarios. Table 10 shows the assumptions and the results of a scenario sensitivity analysis on the Electric Scooter project. As indicated, the results for the three scenarios vary from a very low -R65m to very high R281m in net present value.

SCENARIO SENSITIVITY ANALYSIS	Investment	Variable Cost	Sales	NPV
Pessimistic	165,000,000	3,200	80,000	**-64.81**
Realistic	150,000,000	3,000	100,000	**31.22**
Optimistic	135,000,000	2,600	140,000	**280.86**

<u>Table 10:</u> Scenario Sensitivity Analysis on the Electric Scooter project.

Sensitivity analysis gives the decision-maker an indication of possible losses should circumstances change. The knowledge thus obtained is most useful in identifying the variables that will require careful management or further research.

A criticism of sensitivity analysis is that the work becomes very cumbersome when there are a large number of variables to examine. Whereas sensitivity analysis gives a good indication of the impact of specific variables, it does not give a clear indication of the project's overall risk in such a way that one can explicitly use it in decision-making. The analysis of various scenarios certainly helps, but the results are limited to the number of scenarios examined.

2.4.4 Break-even analysis

Break-even analysis is to some extent just an extension of sensitivity analysis. In sensitivity analysis, one examines the effect of changes in variables on the decision criterion, whereas in break-even analysis one wants to establish the specific parameter value at which point the project becomes unattractive.

For example, if the decision criterion is the net present value (NPV), a parameter's break-even point will be that value where the NPV becomes zero and beyond which the project becomes unacceptable.

Table 11 below shows the results of the break-even analysis for the Electric Scooter project.

VARIABLE	INITIAL ESTIMATE	BREAK-EVEN VALUE
Initial investment amount	R150m	R200m
Fixed annual costs	R30m	R42m
Variable cost per unit	R3,000	R3,112
Sales volume	100,000	85,000

Table 11: Break-even analysis for the Electric Scooter project.

In providing the critical values for each variable, the break-even analysis is very useful.

2.4.5 Monte Carlo simulation

Although very useful, the biggest shortcoming of sensitivity and scenario analysis is that it presents the effects on the decision criterion of only a limited number of combinations of variables. It is this shortcoming that the technique of Monte Carlo simulation addresses in its application to capital projects by presenting the entire range of possible project outcomes in such a way that one is able to identify the most likely outcome and also the spread of possible outcomes around this most likely value. This section will explain the main steps to take in performing a Monte Carlo simulation on a capital project. All steps will be illustrated through a simulation of the Electric Scooter project.

STEP 1: MODELLING THE PROJECT

The first step in the simulation is to develop a model that will project the cash flows as accurately as possible. The model must reflect the interrelationships in the variables from one period to the next and also the interrelationships between variables. Table 3 shows the model that was developed for the Electric Scooter project.

It is also important to use the most appropriate decision criterion and to ensure that its calculation is included in the model. As some decision criteria include margins for risk, it is important with Monte Carlo simulation to exclude all such risk margins, as it is the whole idea of the simulation to express the nature and the extent of the project's risk explicitly. Therefore, if the net present value (NPV) is selected as the decision criterion, one must discount at the risk-free rate and not the opportunity cost of capital, "…because, if you know what that (the opportunity cost of capital) is, you don't need a simulation model …" [Brealy *et al* (1999)].

STEP 2: SPECIFY THE PROBABILITIES

Given the long-term nature of capital projects, the actual future values of most project variables will most probably differ from today's best estimates. Therefore, in addition to providing best estimates for each of the variables, this uncertainty can also be described by means of a statistical probability distribution for each of the variables. In this way, it is possible to indicate:

- The best estimate of each variable;
- The probable range of values for each variable and
- The spread of likely values in each variable's range.

The following three probability distributions should suffice for most variables in capital project models:

i) Uniform distribution;

ii) Normal distribution and the

iii) Triangular distribution.

Uniform distribution

It is appropriate to use the uniform distribution when the variable can take on any value in a certain range with equal probability.

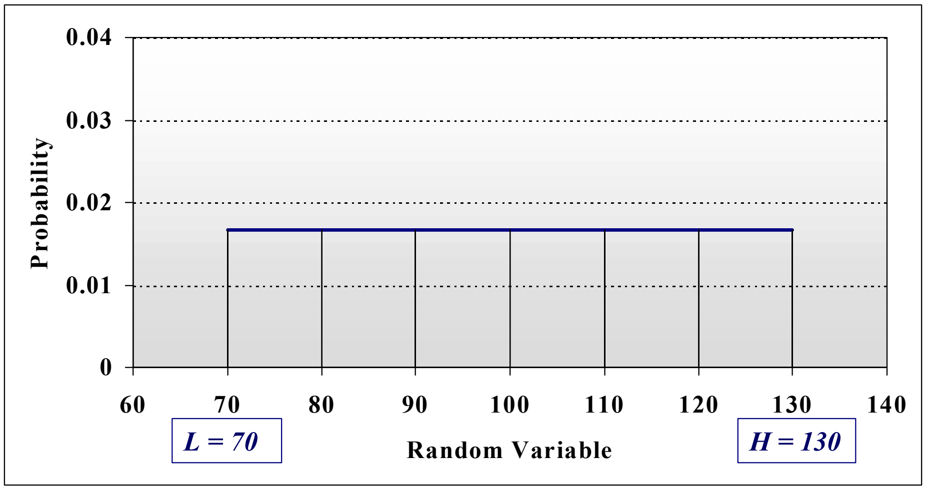
The following parameters must be supplied regarding the variable:

L = the low value in the range.

H = the high value in the range.

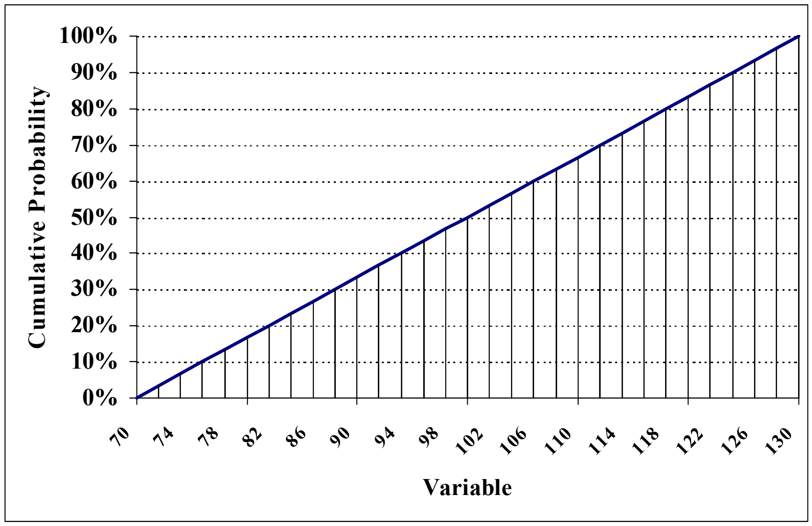
Another way of stating the range is simply to estimate an expected value and the ± range on both sides of the expected value.

Figure 5 shows the uniform probability distribution, with the equal probability of occurrence for all values in the range (i.e. values between L (70) and H(130)):



<u>Figure 5:</u> Uniform Probability Distribution

Another useful way in which to express a probability distribution, is with the *cumulative probability distribution*. The cumulative probability distribution for any specific value of the variable is simply the probability that the actual value of the variable will be less than this specific value. From this description it should be apparent that the cumulative probability distribution can only take on values between 0 and 1. Figure 6 shows the corresponding cumulative probability distribution of the uniform distribution shown in Figure 5.



<u>Figure 6:</u> Cumulative Uniform Probability Distribution

From Figure 6 one can read that there is a 30% probability of the variable having a value of less than 88, also there is a 70% probability that the value of the variable will be less than 113.

Normal distribution

With its familiar bell shape, it is appropriate to use the normal distribution when there is some level of confidence about an expected value for the variable, but where allowance must be made for possible values on both sides of the expected value. The probability of such other values is higher for values close to the expected value and lower for values further from the expected value.

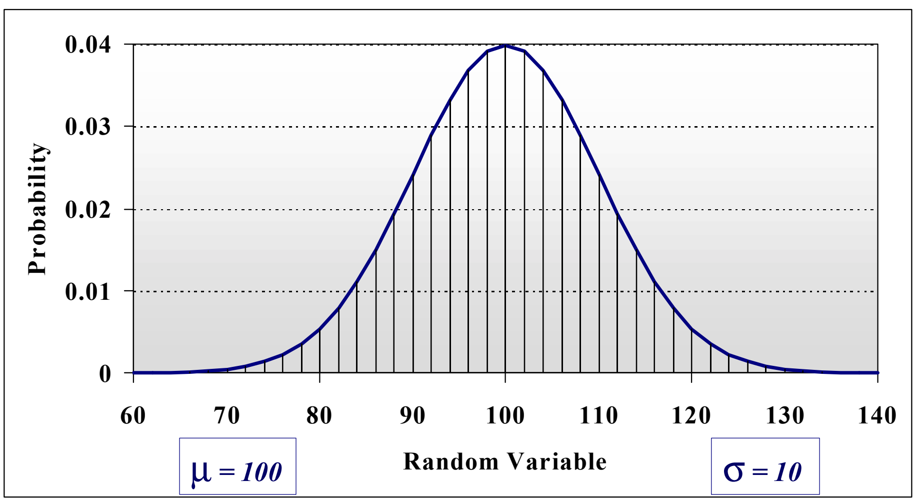
The normal distribution is defined by the following parameters:

$\mu =$ The mean, or the expected value and

$\sigma =$ The standard deviation, which is a measure of the dispersion around the mean.

A practical way of stating the above is simply to estimate an expected value and the ± range on both sides of the expected value. By assuming say that there is a 95% probability that the parameter will assume a value in this range, one can then derive both the mean and the standard deviation.

Figure 7 shows the normal probability distribution, with the highest probability around the mean and the symmetrical bell-shape of lower probabilities on both sides of the mean. The distribution in Figure 7 has the following parameters: a mean, $\mu = 100$ and a standard deviation, $\sigma = 10$.



<u>Figure 7:</u> Normal Probability Distribution

Figure 8 shows the corresponding cumulative probability distribution of the normal distribution shown in Figure 7.

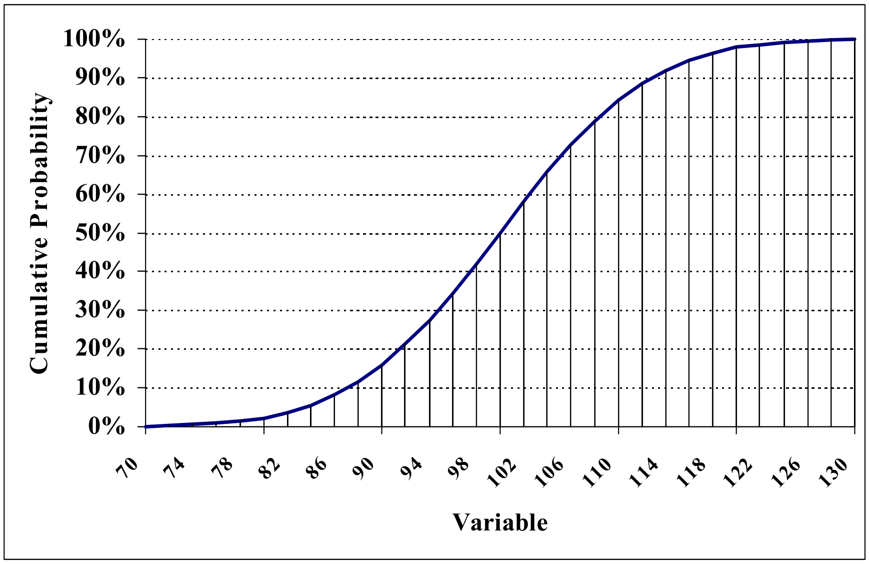


Figure 8: Cumulative distribution of the Normal Probability Distribution

Triangular distribution

Where both the uniform and the normal distributions are symmetrical in shape, the triangular distribution can take on shapes that are either symmetrical or skewed. The triangular distribution is therefore useful when a variable's expected value lies closer to one of the boundaries of the variable's possible range.

The triangular distribution is defined by the following parameters:

L = The lower value of the variable's possible range.

E = The variable's most likely value.

U = The upper value of the variable's possible range.

Figure 9 shows the triangular probability distribution, with the highest probability around the most likely value (E = 80) in a probable range between the lower value (L = 70) and the upper value (U = 130).

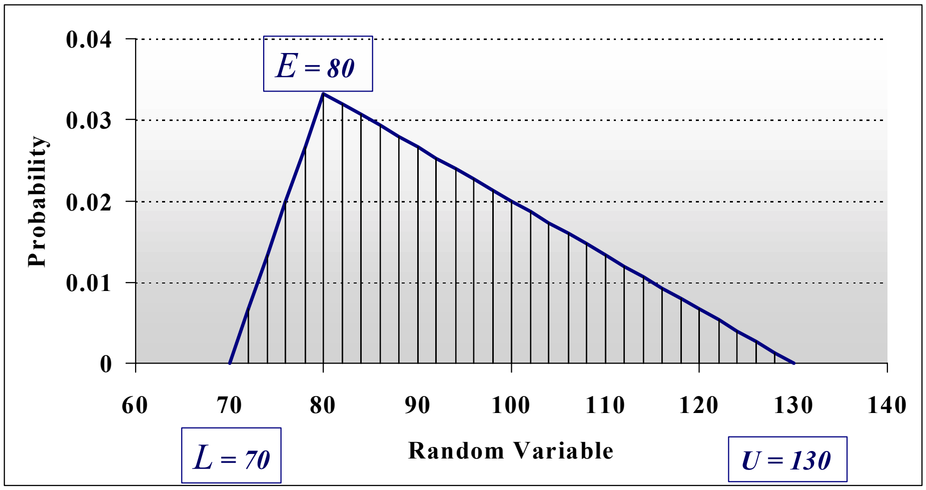


Figure 9: **Triangular Probability Distribution**

Figure 10 shows the corresponding cumulative probability distribution of the triangular distribution shown in Figure 9.

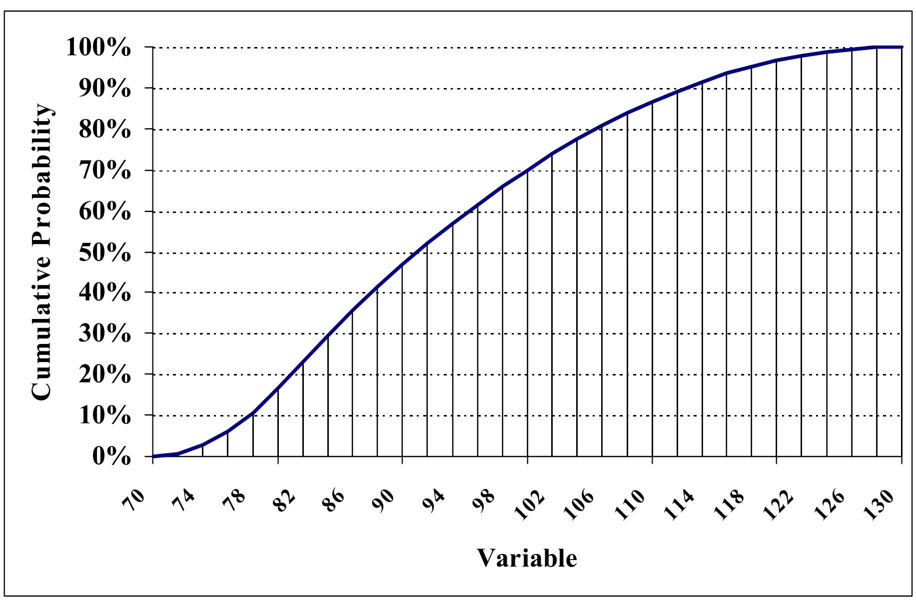


Figure 10: **Cumulative distribution of the Triangular Distribution**

Specifying the Probabilities for the Electric Scooter project

Table 12 below indicates the probability information of some of the key variables in the Electric Scooter project.

Assumptions		Probability detail		
	Estimate	**Distribution**	**2nd parameter**	**3rd parameter**
Investment =	150,000,000	Triangle	130,000,000	210,000,000
Fixed costs =	30,000,000	Uniform	25,000,000	35,000,000
Variable costs per unit =	3,000	Normal	200	
Annual Sales =	100,000	Triangle	75,000	150,000
Price =	3,750			

<u>Table 12:</u> Specification of the probability distributions for key variables in the Electric Scooter project

The initial investment amount has a triangular distribution with a low estimate of R130m, a best estimate of R150m and a high estimate of R210m. The annual fixed costs assume a uniform distribution between R25m and R35m. The variable cost per unit has a normal distribution with an average of R3,000 and a standard deviation of R 200. It is assumed that the annual sales figure has a triangular distribution with a low estimate of 75,000, a best estimate of 100,000 and a high estimate of R150,000.

STEP 3: SIMULATION RUNS

Having specified the probability distributions of the variables, one can now simulate the future cash flows by extracting the values for the variables from the respective distributions. A recognized way of extracting a value from a probability distribution is to generate a random number between 0 and 1 and then by using this number as the cumulative probability, one can derive the variable value by using the corresponding cumulative probability distribution. Each set of variable values thus extracted in effect represents a possible scenario of the future, for which the decision criterion can be calculated.

By repeating this process for a number of times, one gets a range of possible decision criterion values. By calculating the average and the standard deviation, one gets an indication of the most probable value and also the possible spread around the average.

Assumptions		Probability detail			Simulation	
	Estimate	Type	2nd parameter	3rd parameter	Random number	Variable Value
Investment =	150,000,000	T	130,000,000	210,000,000	0.18	147,132,747
Fixed costs =	30,000,000	U	25,000,000	35,000,000	0.73	32,337,788
Variable cost =	3,000	N	3,000	200	0.65	3,079
Annual Sales =	100,000	T	75,000	150,000	0.94	135,189
Price =	3,750					
Tax rate =	50%					
Discount rate =	10%					

Year	0	1	2	3	4	5	6	7	8	9	10
Sales (thousands)		135	135	135	135	135	135	135	135	135	135
Revenue (Rm)		507	507	507	507	507	507	507	507	507	507
Investment (Rm)	-147										
Fixed Costs (Rm)		-32	-32	-32	-32	-32	-32	-32	-32	-32	-32
Variable Costs (Rm)		-416	-416	-416	-416	-416	-416	-416	-416	-416	-416
Depreciation (Rm)		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Pre-tax profit (Rm)		44	44	44	44	44	44	44	44	44	44
Tax (Rm)		-22	-22	-22	-22	-22	-22	-22	-22	-22	-22
Net Cash Flow (Rm)	-147	37	37	37	37	37	37	37	37	37	37

NPV (Rm) = **70.51**

Monte Carlo Simulation

Average NPV = 42.71
Standard Deviation = 73.58

Run:	NPV
1	-88
2	49
3	190
4	196
5	17
6	5
7	55
8	47
9	62
10	-72
11	-7
12	14
13	13
14	174
15	60
16	2
17	141
18	-16
19	-82
20	8
21	137
22	-70
23	90
24	24
25	67
26	-40
27	1
28	-8
29	-25
30	32

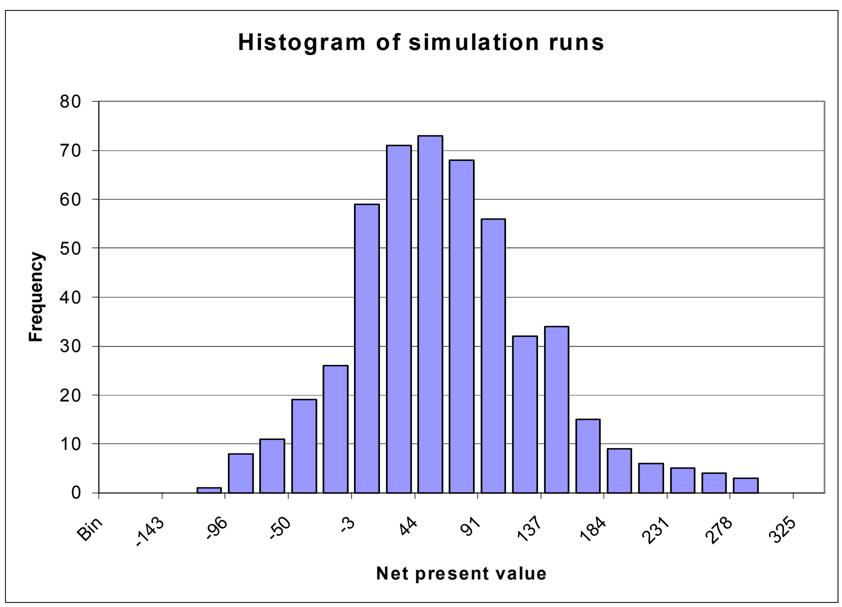


Figure 11: The results of 500 Monte Carlo simulation runs on the Electric Scooter project.

In addition to calculating averages and standard deviations, one can also learn a lot by simply drawing a histogram of the observations. Figure 11 above shows the results of 500 simulation runs done on the Electric Scooter project.

The first section of Figure 11 shows the parameters of the probability distributions for the four variables. Also shown is one simulation run's random numbers between 0 and 1, which are used to extract the variable values from their cumulative probability distributions. These variable values are then used to calculate the decision criterion (in this case NPV) for that simulation run. Shown in Figure 11 are the NPV's for the first 30 simulation runs.

STEP 4: INTERPRETATION

Also shown in Figure 11 is the NPV average and standard deviation of the 500 simulation runs. The histogram of the results of the 500 simulation runs, has a shape similar to the well-known bell-shape of the statistical normal distribution. In this case, it might therefore be reasonable to assume that the NPV of the Electric Scooter project has a normal distribution with an average of R42.71m and a standard deviation of R73.58m.

In many cases the histogram will not approximate the shape of the normal distribution. In such cases, the shape of the histogram might clearly indicate which other distribution would be more appropriate. Even then, it might not be possible to assume a known distribution, in which case one can estimate the risk or the probability of a negative NPV as the number of simulation NPV-results below zero divided by the total number of simulation results.

Figure 12 also shows the normal distribution for the Electric Scooter project and it also shows that the area left of zero is 28%. One can therefore say that the Electric Scooter project has a 28% chance of producing a negative NPV.

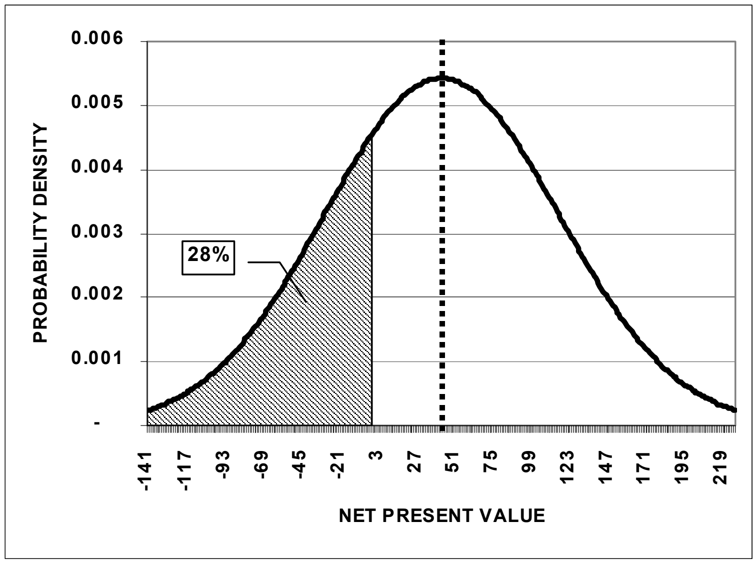
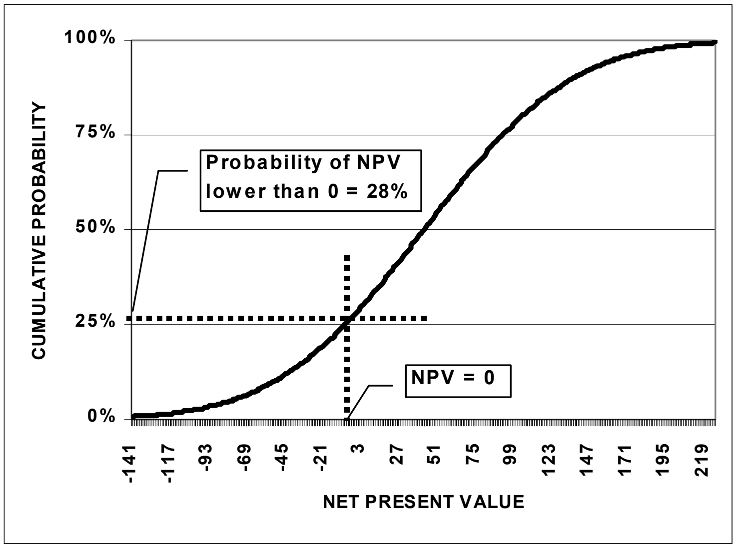


Figure 12: Probability distribution of the Net Present Value of the Electric Scooter project

Figure 13 shows the corresponding cumulative distribution function for the Electric Scooter project. This distribution makes it easy to read off the probability that the NPV will turn out to be negative.



<u>Figure 13:</u> Probability distribution of the Net Present Value of the Electric Scooter project

Even though the Electric Scooter project has a positive NPV, the Monte Carlo simulation provided further insight by indicating a significant probability of failure. This might influence the decision-maker not to commence the project or to authorize further investigation in order to revise the assumptions on the variables and their probability distributions. Alternatively, the decision-maker may decide to go ahead, but then at least with the knowledge that the project is risky and therefore requires focused management.

Advantages of the Monte Carlo simulation method as a way of quantifying project risk:

i) The process of investigating the uncertain variables in order to specify their probability distributions creates a very good understanding of how the project works and of what can go wrong.

ii) Monte Carlo simulation provides a single view of the aggregate impact of all the uncertainties inherent in a project.

iii) The method provides a transparent structure where the decision-maker's view of each variable can be expressed explicitly.

Disadvantages of the Monte Carlo simulation method as a way of quantifying project risk:

i) It can be difficult and costly to describe the various probability distributions.

ii) It is more complicated to perform the simulation than to apply some of the other methods.

2.5 Selection techniques

2.1	Capital projects defined	***Selection techniques*** The objectives of this section are: • To present the current selection techniques available for selecting the best combination of projects. • To discuss the usage and merits of these techniques.
2.2	The capital budgeting process	
2.3	Decision criteria	
2.4	Risk analysis	
2.5	Selection techniques	
2.6	Conclusion	

After all the investigation work has been completed on both the existing and the new projects, the decision-maker must select the best combination of projects taking into account any limitations on resources and capabilities. This section will describe the following techniques that address this problem:

- Capital rationing
- Linear, integer and mixed integer programming
- Analytical hierarchy process

2.5.1 Capital rationing

Companies do not always have all the capital available to finance all the projects that have passed the decision-maker's decision criteria. The identification of the best possible combination of projects can become a complicated task in such circumstances.

One way to do the selection, is to rank the projects in a descending order in terms of the main decision criterion and to select the projects from top to bottom until the capital limitation has been reached. Even though it sounds simple, [Brealy *et al* (1999)] illustrates certain complications with the following example of three projects A, B and C:

	Cash Flows (Rm)				
Project	C_0	C_1	C_2	NPV (@ 10%)	Profitability Index
A	-10	30	5	21	2.1
B	-5	5	20	16	3.2
C	-5	5	15	12	2.4

<u>Table 13:</u> Capital rationing example

In Table 13 C_0, C_1 and C_2 denote the net cash flows at the start of the projects and after one and two years respectively. Table 13 also shows the NPV for each project and also another criterion called the Profitability Index, which is calculated as follows:

$$Profitability\ Index = \frac{Net\ present\ value}{Investment}$$

The Profitability Index is therefore an indication of the highest net present value per unit of capital invested.

In the example, the decision-maker has an investment capital constraint of R10m. When using the NPV-rule, the decision-maker will select the first project, namely project A as it provides the highest NPV and since its investment amount corresponds to the constraint of R10m. However, when using the profitability index as the criterion, the order of the projects changes to: B, C, A. Since the total investment capital for projects B and C amounts to R10m, the decision-maker will choose them instead of project A. It is therefore important to select the most appropriate decision-criterion, when selecting projects under conditions of limited capital.

The most important limitation of the capital rationing ranking technique is that it can only be applied without complications when there is only a limit on the initial capital amount. [Brealy et al (1999)] illustrated this limitation by expanding the above example to cases where there are also capital requirements and limitations on the available capital in the second year. The technique can also not cope with the situation where one project is dependent on another.

2.5.2 Linear, integer and mixed integer programming (LP)

Linear programming is an optimization technique that is very useful in capital budgeting problems as it produces an optimal solution while taking account of many constraints. In 1947 George Dantzig developed the simplex algorithm for solving linear programming problems. According to [Winston (1994)] LP has been used to solve optimization problems in many industries. A survey of Fortune 500 companies indicated that 85% of the responding companies had used LP.

In this section the use of linear programming is illustrated by way of an example, based on the projects in Table 14.

	Cash Flows (Rm)			
Project	C_0	C_1	C_2	NPV (@ 10%)
A	-10	30	5	21
B	-5	5	20	16
C	-5	5	15	12
D	0	-40	60	13

Table 14: Projects in linear programming example from [Brealy et al (1999)].

In this example, the decision-maker has to select the best combination of projects subject to the limitation on the net cash outflow for period 0 of R10m and also a R10m limitation on the net cash outflow for period 1.

The first very important component of any linear programming application is the *objective function*, which is the value that the decision-maker must either maximize or minimize. In this example it is assumed that the decision-maker wishes to select that combination of projects that will maximize the NPV.

If one defines x_A as the proportion of project A that is selected by the linear program, then one can say that the resultant NPV-contribution of this choice is $21x_A$. One can also limit the value of x_A to be between 0 and 1, which means that one cannot select a negative portion of a project and also that one cannot select a portion greater than 1 of a project. In a linear program this x_A is called a *decision variable*. In the same way, one can define the other decision variables x_B, x_C and x_D as the respective proportions selected of projects B, C and D in order to maximize the overall objective function.

Given these decision variables and the NPV's for each project (see Table 14), one can now formulate the *objective function* as follows:

$$\text{Maximize } NPV = 21\,x_A + 16\,x_B + 12\,x_C + 13\,x_D$$

The first *constraint* in this example is that the total cash outflow in period 0 must not exceed R10m. Table 14 also shows the net cash flow for each project in period 0. The selection of the projects is therefore subject to the following constraint:

$$10\,x_A + 5\,x_B + 5\,x_C + 0\,x_D \leq 10$$

The second constraint requires that the total cash outflow in period 1 must also not exceed R10m. This constraint can therefore be formulated as follows:

$$-30\,x_A - 5\,x_B - 5\,x_C + 40\,x_D \leq 10$$

Finally the linear program also requires that one specify the value ranges of each of the decision variables, as follows:

$$0 \leq x_A \leq 1, \quad 0 \leq x_B \leq 1, \quad 0 \leq x_C \leq 1 \text{ and } 0 \leq x_D \leq 1$$

Table 15 shows both the structure and the solution of the above linear programming example. The *What's Best* add-in for Microsoft Excel (developed by Lindo Systems) was used to solve this linear programming example.

Project	Decision variables		
A	0.50		
B	1.00		
C	-		
D	0.75		
Objective Function:			
Maximize total NPV =	36.25		
Constraints:	Value	Limit	Relation
Cash outflow in period 0 =	10.00	10	=<=
Cash outflow in period 1 =	10.00	10	=<=
Decision variable for project A =	0.50	1	<=
Decision variable for project B =	1.00	1	=<=
Decision variable for project C =	-	1	<=
Decision variable for project D =	0.75	1	<=

Table 15: Example of a linear programming example.

The solution to the above problem is therefore that a maximum total NPV of R36.25m can be achieved by selecting a half of project A, the full project B and three-quarters of project D. Table 15 also shows how all the constraints are satisfied.

The main advantage of linear programming is that it gives one the optimal solution for a typical selection problem where the solution has to satisfy a number of constraints. In the past it was necessary to write costly and complicated programs in order to solve linear programming problems, but today most spreadsheets come with the functions that can solve linear programming problems.

It might not always be possible to select fractional projects, as suggested by the solution in Table 15. Many capital projects can only be implemented as wholes and not as fractions. This would require that the model ensure that the decision variables remain either 0 or 1. The solution of such a situation is known as *integer programming* (IP). IP is therefore just an LP problem, but with the only difference that the decision variables can either take on values of 0 or 1. Table 16 shows the solution for the integer programming problem.

Project	Decision variables		
A	-		
B	1.00		
C	1.00		
D	-		
Objective Function:			
Maximize total NPV =	28.00		
Constraints:	Value	Limit	Relation
Cash outflow in period 0 =	10.00	10	=<=
Cash outflow in period 1 =	-10.00	10	<=
Decision variable for project A =	-	1	<=
Decision variable for project B =	1.00	1	=<=
Decision variable for project C =	1.00	1	=<=
Decision variable for project D =	-	1	<=

<u>Table 16:</u> Example of an integer programming problem.

With the selection of projects B and C, the total NPV drops by 23 % to R28m as a result of the requirement that the decision variables are now either 0 or 1.

Note that some of the decision variables could be integer while some others could assume fractional values. This is known as a *mixed integer programming problem*.

2.5.3 Analytical hierarchy process (AHP)

AHP is a technique that can be applied in the capital budgeting process as it enables the decision-maker to prioritize the investment opportunities. AHP not only takes account of the financial aspects but it enables the decision-maker to also take into account qualitative and intangible factors such as public perception, staff morale, safety, service enhancement and political benefits.

Thomas Saaty developed the AHP technique for use in decisions where there are multiple objectives. AHP can certainly be applied in capital budgeting, since the decision-maker must simultaneously give consideration to multiple factors.

AHP can work as follows in capital budgeting:

- Multiple objectives: The first step is to identify all the objectives that the selected projects must support.
- Relative importance of objectives: AHP applies a pairwise comparison process with consistency checks in order to arrive at weights for each of the objectives. The objective's weight is an indication of its relative importance.
- Project scores per objective: The next step is to assess and score each of the projects in respect of each objective.
- Total project score: Given the weights for the different objectives and the project scores per objective, one can then calculate an overall score for each project.
- Overall ranking of the projects: The projects can now be ranked according to their total scores.

To illustrate the AHP, consider the company Freesia Industries that want to rank the six projects A, B, C, D, E and F in terms of the following multiple objectives:

- Economic feasibility
- Health and safety
- Customer satisfaction
- Reputation in the market
- Social responsibility

The first step will be to determine the relative importance of these multiple objectives in respect of capital budgeting. Freesia Industries has to complete the **pairwise comparison matrix** (see Table 18) where each of the objectives is compared to all the others and where they have to decide on the values a_{ij}, that indicates by how much objective i is more important than objective j. Table 17 explains the interpretation of the values that can be entered into the pairwise comparison matrix.

Comparison Value a_{ij}	**Interpretation**
1	Objectives i and j are of equal importance.
3	Objectives i is weakly more important than objective j.
5	Experience and judgement indicate that objective i is strongly more important than objective j.
7	Objectives i is very strongly or demonstrably more important than objective j.
9	Objectives i is absolutely more important than objective j.
2,4,6,8	Intermediate values when the importance lie midway between the above interpretations.

Table 17: Interpretation of entries in a pairwise comparison matrix [Winston W. L. (1994)]

Table 18 shows the pairwise comparison matrix completed by Freesia Industries.

	Economic	Safety	Customer	Reputation	Social
Economic	1.00	4.00	8.00	9.00	9.00
Safety	0.25	1.00	2.00	3.00	6.00
Customer	0.13	0.50	1.00	2.00	3.00
Reputation	0.11	0.33	0.50	1.00	1.50
Social	0.11	0.17	0.33	0.67	1.00

<u>Table 18:</u> Pairwise comparison matrix for the multiple objectives of Freesia Industries

Table 18 shows the relationship between the objective in the left-hand column and the objective in the heading of a specific column. For example, to determine the relative importance of "Economic Feasibility" over "Health and Safety", one locates the "Economic" row and moves right to the "Safety" column where a value of "4" is found. It is therefore the view of Freesia Industries that "Economic Feasibility" is four times as important as "Health and Safety" in respect of capital budgeting. The inverse also applies as the relative importance of "Health and Safety" over "Economic Feasibility" is indicated as 0.25 or ¼.

[Winston W.L. (1994)] provides a detailed description of the AHP-method and also shows how to implement AHP on a spreadsheet. By applying statistical consistency checks to the pairwise comparison matrix, the AHP-method indicates whether the logic in the matrix is consistent or not. If it found to be inconsistent, one can revise the entries until a consistent structure is found.

Once the pairwise comparison matrix is consistent, the AHP-method calculates the weights of the objectives in terms of importance (see Table 19).

Objective	Weight
Economic feasibility	60%
Health and safety	20%
Customer satisfaction	10%
Reputation in the market	6%
Social responsibility	4%

Table 19: Weights in terms of importance of the multiple objectives for Freesia Industries

The next step is to weigh the different projects in terms of each objective. Since economic feasibility is the only tangible objective in terms of measurement, one can use the selected decision criterion for the ranking of the projects in respect of this objective. Freesia Industries uses NPV as their criterion for economic feasibility. Table 20 shows how one can use the calculated NPV's to determine the project weights in respect of economic feasibility.

	NPV (Rm)	Weight	Ranking
Project A	23	27%	1
Project B	10	12%	5
Project C	18	21%	2
Project D	12	14%	4
Project E	6	7%	6
Project F	16	19%	3
	85		

Table 20: Ranking of projects in terms of economic feasibility.

Each project's weight in Table 20 is equal to the ratio of its NPV to the sum of all the projects' NPV's. For example, the weight of project A is equal to 23 / 85 = 27%.

The other objectives are intangible and it is more difficult to determine the project weights for these objectives. For this one can again complete a pairwise comparison matrix for each objective where the projects are compared to each other in terms of the specific objective. The AHPmethodology confirms the consistency of each matrix and determines the project weights per objective. When this is done for each objective, the results can be presented as in Table 21.

	OBJECTIVES					
	Economic feasibility	**Health and safety**	**Customer satisfaction**	**Reputation in the market**	**Social responsibility**	
Weights of objectives	**60**	**20**	**10**	**6**	**4**	**AHP Score**
Project A	27%	12%	9%	43%	5%	22.32
Project B	12%	34%	11%	7%	24%	16.34
Project C	21%	18%	12%	23%	12%	19.37
Project D	14%	7%	40%	12%	11%	15.03
Project E	7%	23%	17%	7%	45%	12.76
Project F	19%	6%	11%	8%	3%	14.19
	100%	100%	100%	100%	100%	100.00

Rank	**Project**	**AHP-Score**
1	Project A	22.32
2	Project C	19.37
3	Project B	16.34
4	Project D	15.03
5	Project F	14.19
6	Project E	12.76

Table 21: Ranking of projects for Freesia Industries

Table 21 presents the final order of the projects in terms of the company's multiple objectives. It is interesting to note how the order has changed from Table 20 where only economic feasibility was considered to the final order in Table 21 where all the objectives were taken into account. Note how Project B moved up from the 5^{th} to the 3^{rd} position. The main reason for this must be the fact that this project has the highest weight for health and safety, which is also the most important objective after economic feasibility.

Advantages of AHP:

i) AHP provides a structured and transparent way of accounting for qualitative and intangible factors that are often overlooked by other techniques.

ii) AHP can accommodate large numbers of criteria, subcriteria and alternatives.

iii) The process of pairwise comparison often results in different points of view amongst management. As consensus is required, there is a lot of value in the debates, which certainly contributes to the clarification and understanding amongst management of which factors are more important than others.

iv) The participation of management in the process leads to easier acceptance of and buy-in into the eventual decisions.

Disadvantages of AHP:

i) AHP is a fairly involved technique and the participants often require some educating in the method.

ii) The pairwise comparison procedure quickly becomes very time-consuming as the number of objectives and alternatives increase.

iii) Whereas AHP can order projects in terms of multiple objectives, it does not optimize the selection of capital projects where a number of physical constraints are present.

2.6 Conclusion

2.1	Capital projects defined	***Conclusion*** The objective of this section is to formulate the requirements for an integrated approach to capital budgeting that will achieve and maintain the optimal portfolio of capital projects while also addressing the shortcomings of the current techniques.
2.2	The capital budgeting process	
2.3	Decision criteria	
2.4	Risk analysis	
2.5	Selection techniques	
2.6	Conclusion	

The main difficulty with the assessment, selection and management of capital projects lies in the complexity, caused by so many different factors that impact on the eventual outcomes. Before approving such capital projects, careful consideration is given to the detailed feasibility studies. For such projects to be successful, the actual outcomes must compare favorably to the assumptions in the feasibility studies. Sound continuous management of the capital projects, under changing circumstances, is therefor a critical success factor for the future viability of the company and the wealth of its shareholders and for the interests of all its stakeholders. Many companies assess capital projects on an individual project basis by calculating the relevant economic measures and, based on the outcome, then decide whether to proceed or not. In this dissertation a portfolio management approach is proposed whereby, instead of only focusing on the individual projects, one rather attempts to identify the optimal combination of both current and new capital projects that will maximize the future value of the portfolio of projects.

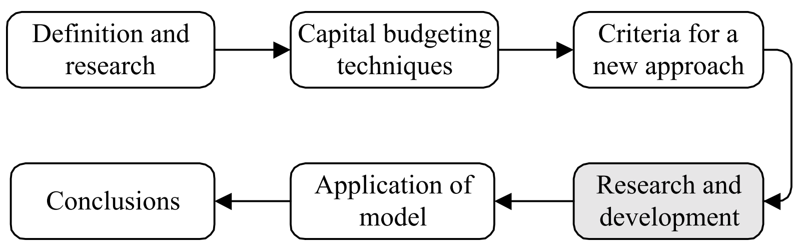
It is the premise of this dissertation that the approach to the solution of the problem of capital projects can be improved by integrating the most appropriate techniques and by applying the principles of portfolio theory and portfolio management. Therefore, in addition to considering the individual merits of the different projects, it will be shown that a better solution can be found when one also considers the characteristics of the selection (or portfolio) of projects. In Chapter 3 such an integrated model will be developed. This model will at least address the shortcomings of the current techniques and will also endeavor to address additional features that will simplify the process of initial selection and continued management of a company's portfolio of capital projects. This model will ensure that both the initial selection and the continued management of a company's capital projects are done in such a way that it adheres to the following requirements:

i) The model must ensure that the selection of capital projects supports the company's strategic objectives.
ii) The model must enable one to quickly indicate the impact on the portfolio of projects of any changes in the economy and industry that the company operates in. Such changes can result in the termination or postponement of existing projects or in the commencement of some new projects such that the new combination of projects is the optimal one given the new circumstances.
iii) The model must take account of the company's financial and physical capabilities and capacities.
iv) The model must take account of any interdependencies amongst different projects (for example when one project can only be included if another is excluded or when one can only be included if another is included).
v) The model must enable one to reflect the overall risk level of the portfolio of projects. In order to do this, one should be able to indicate the correlation in terms of returns that there might exist between the different projects.
vi) The model must be able to cater for the subjective experience and judgement of management.
vii) The model should also enable the measurement of progress and should provide input for use in the regular reviews of the composition of the portfolio of capital projects.

viii) The model must be able to account for the many qualitative and intangible factors involved in the decision-making process.

DEVELOPMENT OF AN INTEGRATED CAPITAL BUDGETING MODEL

The objective of this chapter is to develop a capital budgeting model that will optimize and address the current problems with the capital budgeting process through an approach that will integrate the analysis, selection and the continued management of a company's existing and new capital projects. Figure 14 highlights this objective in relation to the overall approach for the dissertation.



<u>Figure 14</u>: The objectives of chapter 3 in relation to the overall approach for the dissertation.

It is the premise of this dissertation that this integration and optimization can be achieved by applying the principles of portfolio theory and portfolio management. In addition to examining the characteristics of the individual projects, the model must therefore focus on the behaviour of the portfolio of projects.

The chapter starts by considering the basics of portfolio theory and continues with the development of a portfolio mandate and the consideration of the impact that this approach has on the way in which the projects are modeled. Attention is given to the assumptions in the model, the inputs that will be required for each project and how to deal with uncertainties in the assumptions and the inputs. The chapter shows how each project can be analyzed and how to introduce portfolio and other constraints and also how to ensure that the portfolio adheres to the company's strategy. There is a detailed description of how to ensure that the portfolio risk remains within acceptable limits. The chapter concludes by describing how the model selects the final portfolio and once implemented, how the portfolio can be managed in order to maintain the optimal solution under changing circumstances.

3.1 Portfolio theory and capital projects

Portfolio Theory and capital projects

The objectives of this section are:
- To provide an overview of portfolio theory.
- To indicate what aspects can be applied to the selection and management of a portfolio of capital projects.

Due to various limitations (e.g. limited availability of capital; limited capacity in the company to successfully undertake additional work) it is not always possible to implement all the projects that have passed the evaluation stage. Hence the need in the selection stage to approach the problem of selection from a *portfolio point of view*, where the objective is to select the best subset of projects given the company's strategy and limitations.

According to Wilkes (1978), *"Portfolio Theory is concerned with the problem of selecting (and in general building and revising) an optimal set of investments (the portfolio) bearing in mind the anticipated returns to these investments, the risk associated with them and the utility of the investor"*

This description covers the following key aspects of portfolio management:

i) *"selecting"*: This is the process of selecting those projects that will best contribute to the attainment of the company's goals, given the constraints under which the choices must be made. The outcome of this process is the company's portfolio of capital projects.

ii) *"optimal set"*: For the portfolio to be optimal, the selected projects must be the best combination for attaining the company's objectives. The objective is to select the optimal portfolio of projects. This is not the same as selecting the best individual projects.

iii) *"anticipated returns"*: Maximizing investment returns is usually one of the most important objectives in the management of a portfolio of capital projects. *"Returns"* however can also refer to benefits that are not always quantifiable in monetary terms.

iv) *"risk ... and the utility of the investor"*: While the objective is usually to maximize the returns and benefits arising from the company's capital projects, this cannot be done at the expense of exposing the company to such a level of risk that the company's future is thereby compromised. It is therefore crucial that cognizance is taken both of the risks inherent in each project and of the company's capacity for risk exposure. Since the individual projects will respond differently to changing circumstances (in a given set of circumstances some will do better than others), it is very important to examine the risk characteristics of the portfolio as a whole.

v) *"building and revising"*: This is the very important on-going process of review and assessment of whether the chosen portfolio of capital projects is still the optimal one. In this process the company must assess the progress of the projects that are underway, the attractiveness of any new projects and the impact of changes in the economy, the industry and the political environment. The outcome of this process will be changes to the portfolio such that the new portfolio is then the optimal one, given the new set of circumstances, knowledge and experience.

The portfolio-approach to the selection of capital projects can result in decisions that differ from the decisions taken when comparing projects on a one-to-one basis. For example, when using the Net Present Value (NPV) rule, Project A is preferred to Project B if $NPV_A > NPV_B$. However in a portfolio context Project B might be selected as its cash flow pattern might optimize the portfolio by for example releasing cash flows at a time when capital is needed to undertake other feasible projects. Project B might also be a prerequisite for say Project C, such that the combination of projects B and C is preferred to Project A.

It is therefore important, in order to identify the optimal portfolio of projects, that the decision-maker, in addition to analyzing the individual projects, also considers the behaviour of the portfolio of projects.

3.2 An integrated optimization model

3.1	Portfolio theory and capital projects	***An integrated optimization model*** The objective of this section is to provide an overview of an integrated approach to finding the optimal portfolio of capital projects.
3.2	An integrated optimization model	
3.3	Assumptions in the model	
3.4	Economic feasibility of projects	
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

Figure 15 shows the main components of an integrated optimization model that produces the optimal portfolio of capital projects and addresses the shortcomings of the current techniques.

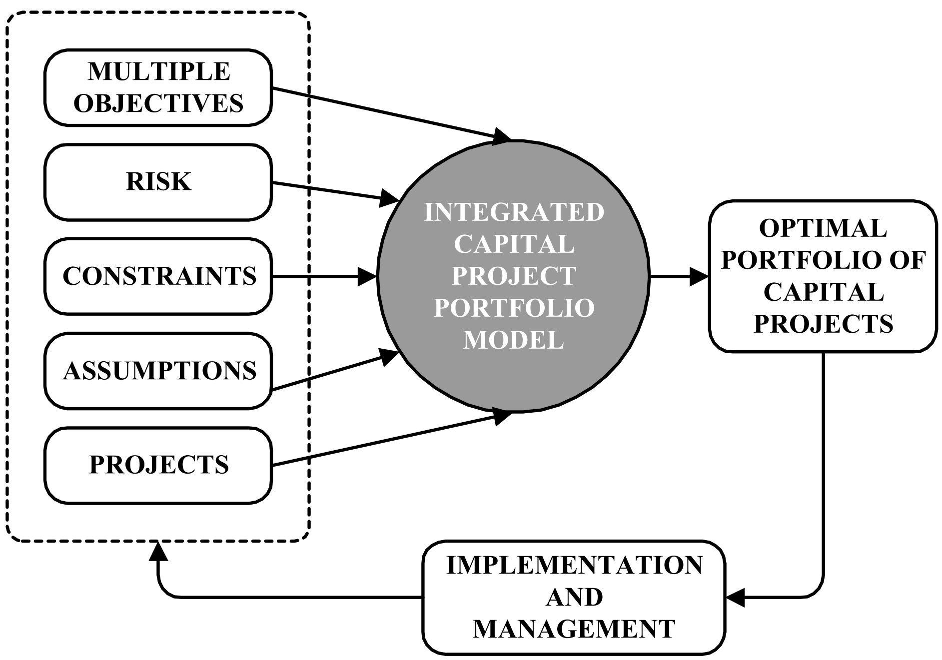


Figure 15: Components of the integrated capital project portfolio model.

Below follows a brief description of each of the model's components

Output of the model: Optimal portfolio of capital projects

The output of the model is a set of decisions regarding the optimal composition of the company's portfolio of new and existing capital projects. The model must indicate "start / do not start" decisions regarding the new projects and "continue / delay / terminate" decisions regarding existing projects. The optimal portfolio is attained by maximizing value to the company in terms of the quantitative/tangible and qualitative/intangible multiple objectives and by adhering to all constraints and risk requirements.

Multiple objectives

A key short-coming of the current capital project budgeting techniques is that the decision criterion is a financial one (e.g. the internal rate of return, net present value, payback period, etc.). Companies however do not operate in financial vacuums where the wealth of the shareholder is the only objective, but they operate in environments where there are other objectives that are also important. Examples of such other objectives are customer satisfaction, staff morale, product quality, health and safety, social responsibility, environmental conservation, brand value, perceptions in the market place, supplier relationships and others.

This model addresses this problem by having a composite function that consists of multiple objectives and by selecting the projects in such a way that this multiple objective function is optimized.

The decision-maker must identify all the objectives to be considered in the company's decisions regarding capital projects. Once identified, the decision-maker is prompted to indicate the relative importance of the multiple objectives in terms of the capital budgeting decision. It is imperative that employees that have a very clear understanding of the company's strategy give this input. If the interpretation of the company's strategy is wrong, the model might recommend decisions that will not support the company's strategic vision. Based on this input, the model attaches weights to the objectives that indicate their relative importance. These weights will ensure that the appropriate preference is given to those projects that do not necessarily stand out in terms of economic benefits but that also contribute more in terms of the non-economic intangible objectives.

Risk

Risk in terms of this model is defined as the probability that a capital project is not profitable. In this context, profitability relates to a project's ability to generate returns in excess of the sum of the company's cost of capital plus its minimum acceptable profit margin.

In this model, risk is considered both on the project and on the portfolio levels. On the project analysis level, the company should determine the risk of each project and should at this stage already decline those projects that appear to be too risky. On the portfolio level, the model also gives an indication of the portfolio risk, in other words the probability that the portfolio of products will generate unacceptable low returns. By specifying the company's minimum acceptable level of portfolio risk, the decision-maker can ensure that the risk of the chosen portfolio of projects will be within acceptable norms.

Constraints

The company can only implement a portfolio of capital projects if careful account is taken of its own capabilities and capacities. The decision-maker must take great care in formulating the financial, physical and other *constraints* so that the output of the model can be feasible.

Assumptions

All capital budgeting decisions are based on analyses of projections of future cash flows. As a first step one must identify all the variables that will determine the future cash flows. It is important to understand the interrelationships between these variables and to develop the model in such a way that these relationships always apply. In order to produce these projections of the future cash flows, it is necessary to make *assumptions* about these variables. In this model the decision-makers not only make best-estimate assumptions, but also describe the extent and the nature of the uncertainties concerning the variables. Although many aspects about the future are very uncertain, the set of assumptions is at least an indication of how the decision-makers view the future and the model will ensure that the final portfolio is the optimum for this view of the future.

Projects

The model requires the following input in respect of the projects:

- The outstanding projected cash flows of the existing and the new projects.
- Each project's score in terms of each of the multiple objectives.
- The detailed project assumptions.
- The detailed descriptions of the uncertainties in certain variables.
- The logical relationships amongst the projects (e.g. when project A can only start if project B has been selected; when only one of projects C, D and E can be selected; etc.).

Optimization

The *What's Best* add-in for Microsoft Excel (developed by Lindo Systems) will be used for the *portfolio optimization.* This software can be used to solve both linear, non-linear and integer programming problems in a spreadsheet and was found to be suitable for this application.

Implementation and management

It is important for management to carefully analyze and review the output of the portfolio optimization. Management must be satisfied that the proposed portfolio is the best one for the moving the company towards its strategic vision. There might for example be some constraints that can be adjusted and the model enables one to study the impact of constraint changes on the overall outcome of the portfolio. After the portfolio has been implemented, many changes (e.g. economic, industrial, strategic, regulatory or even the identification of new projects) can prompt the company to re-assess the composition of its portfolio of capital projects. Once the company is satisfied with the significance and permanence of these changes, the model can be re-populated with the latest information and can recommend the changes that must be made to the portfolio in order for it to be optimal. The implementation of such changes will again be subject to management approval.

3.3 Assumptions in the model

<table>
<tr><td>3.1</td><td>Portfolio theory and capital projects</td><td rowspan="10">Assumptions in the model

The objectives of this section are as follows:
• To describe the types of assumptions necessary for capital budgeting, from macroeconomic to project-specific.
• To explain how to include the assumptions in the model.
• To explain how to deal with uncertainties in the assumptions.</td></tr>
<tr><td>3.2</td><td>An integrated optimization model</td></tr>
<tr><td>3.3</td><td>Assumptions in the model</td></tr>
<tr><td>3.4</td><td>Economic feasibility of projects</td></tr>
<tr><td>3.5</td><td>The multiple objective function</td></tr>
<tr><td>3.6</td><td>Risk analysis of projects</td></tr>
<tr><td>3.7</td><td>Risk analysis of the portfolio of projects</td></tr>
<tr><td>3.8</td><td>Constraints</td></tr>
<tr><td>3.9</td><td>The optimal solution</td></tr>
<tr><td>3.10</td><td>Portfolio management</td></tr>
</table>

All capital budgeting decisions are based on analyses of projections of future cash flows. In order to produce these projections, one must identify and estimate all the variables that will determine these future cash flows. It is important to understand the interrelationships between these variables, as some variables (called *endogenous variables* [Tennent *et al* (2001)]) can be derived from within the model. The other variables that are direct inputs into the model and that cannot be determined through the use of formulae and other inputs are called *exogenous variables*.

Given the far-reaching impact of capital budgeting decisions, it is critical for the company to obtain the best available intelligence in order to derive the most *accurate* estimates regarding the future. There are however numerous examples worldwide of capital projects where the projections have been significantly inaccurate, for example according to [Wendell Cox Consultancy (1998)]:

i) The costs for the Channel Tunnel between England and France were originally projected at $7.8bn, but escalated to $18.6bn - an increase of nearly 140%!

ii) The costs for the New Denver International Airport were originally projected at $1.7bn, but escalated to $4.8bn - an increase of about 280%!

These inaccurate forecasts were made despite the availability of a wealth of data and experience. It therefore illustrates how critical it is to produce accurate forecasts and also suggests that the company should take into account its own ability to forecast accurately.

A very important aspect of the model's assumptions and inputs is *consistency*. In respect of this model, *consistency* means that all the variables that relate to others, should always be allocated values that adhere to such interrelationships. An important example is the relationships of many items to the exchange rate. Changes in the exchange rate will certainly influence demand and also the costs of production. Once all the variables have been identified, it is important to determine how and to what extent the variables relate to each other. These relationships must be captured in the model so that the model output will always be consistent irrespective of which variables are changed.

Most cash flow items are really just best estimates of unknown future values. In statistical terminology such items are called *random variables*, as their eventual values will most probably differ from the initial estimates. The model must therefore be able to deal with *risk* and *uncertainties*.

The rest of this section will describe the typical assumptions, such as macroeconomic and project-specific, and will then describe how to deal with the risk and uncertainties regarding the variables.

Macroeconomic assumptions

Any analysis or examination of capital projects must be based on the company's official view of the macroeconomic environment that it operates in (often called the "House View"). House Views typically provide projections on both local and international macroeconomic variables. As capital projects are very long-term in nature, it is important for these House Views to provide forecasts that cover such long periods.

[Tennent J et al (2001)] defines *macroeconomics* as the study of the economy as a whole that focuses on the interaction of large-scale, aggregated variables. They also describe how to accommodate the following commonly used variables in business models:

i) Gross domestic product
ii) Inflation
iii) Interest rates
iv) Exchange rates
v) Population

Gross domestic product (GDP) and Business Cycle

A country's GDP is defined as the total value of goods produced and services provided in one year. The GDP growth rate is the rate of change in the GDP from one year to the next.

The GDP growth rate has the following two important characteristics:

i) GDP growth rates do not change dramatically from year to year and
ii) The growth rates generally follow a cyclical pattern - known as the *business cycle*.

There is a close correlation between the business cycle and other macroeconomic variables such as inflation, exchange rates and interest rates. As the business cycle is an indicator of economic prosperity, it can be used to derive estimates for other variables such as imports, exports and market demand.

[Tennent J et al (2001)] presents and illustrates the use of a sine curve model for the forecasting of the business cycle. This approach takes the following characteristics into account:

i) The average expected cycle length.
ii) The present stage of the business cycle.

iii) The change over time of the underlying GDP growth rate.

iv) The expected variations in the cycle from its lowest to its highest points.

Since World War II to the end of 1999 the South African economy went through 14 complete business cycles. The average cycle length over this period was 3 years 9 months, with the shortest cycle being 1 year 10 months and the longest 7 years 2 months. See Table 22.

Trend	Start	End	Cycle Length (months)		
			Up	Down	Total
Up	Jan 1945	Jul 1946	18	8	26
Down	Aug 1946	Apr 1947			
Up	May 1947	Nov 1948	18	14	32
Down	Dec 1948	Feb 1950			
Up	Mar 1950	Dec 1951	21	14	35
Down	Jan 1952	Mar 1953			
Up	Apr 1953	Apr 1955	24	16	40
Down	May 1955	Sep 1956			
Up	Oct 1956	Jan 1958	15	13	28
Down	Feb 1958	Mar 1959			
Up	Apr 1959	Apr 1960	12	15	27
Down	May 1960	Aug 1961			
Up	Sep 1961	Apr 1965	44	7	51
Down	May 1965	Dec 1965			
Up	Jan 1966	May 1967	16	6	22
Down	Jun 1967	Dec 1967			
Up	Jan 1968	Dec 1970	36	19	55
Down	Jan 1971	Aug 1972			
Up	Sep 1972	Aug 1974	23	40	63
Down	Sep 1974	Dec 1977			
Up	Jan 1978	Aug 1981	44	18	62
Down	Sep 1981	Mar 1983			
Up	Apr 1983	Jun 1984	14	20	34
Down	Jul 1984	Mar 1986			
Up	Apr 1986	Feb 1989	35	51	86
Down	Mar 1989	May 1993			
Up	Jun 1993	Nov 1996	42	32	74
Down	Dec 1996	Aug 1999			
		Average =	26	20	45

Table 22: Business cycle phases in South Africa since 1945 (source: South African Reserve Bank *Quarterly Bulletin*, March 2004)

Inflation

It is useful to have forecasts for inflation in a capital budgeting model, as other important variables can be derived from inflation, such as forecasts for market size, exchange rates, prices and costs.

Inflation is the rate at which the price of a defined basket of goods changes from one year to the next and is therefore an indication of the general price levels of goods and services. Indices have been developed to measure inflation, the most common index is the CPI, the consumer price index. There are however other industry of sector-specific indices that might be of more use to a company or to a specific project.

There are many factors that determine a country's inflation rate. An important determinant is economic activity, which is indicated by the business cycle. [Tennent J et al (2001)] describes the relationship between economic activity and inflation as follows:

i) As *economic activity grows*, general incomes increase which leads to higher demand for goods and services. When the demand for goods and services rises the prices are bid up (*higher inflation*) as the supply of goods and services is assumed to respond more slowly to the changes in demand.

ii) A *slowing down in economic activity* will lead to lower increases in income, which will lead to lower demand for goods and services. As the supply of goods and services is assumed to respond more slowly to the changes in demand, the lower demand will result in excess supplies, which will have downward pressure on prices (*lower inflation*).

[Tennent J et al (2001)] presents and illustrates the use of a sine curve model for the forecasting of inflation. The following approach is presented:

i) To assume a comparatively stable trend in inflation, with variations around this trend.
ii) The variations around the trend are related to the peaks and troughs of the business cycle, which has already been modeled in the GDP-growth.
iii) To accommodate the delay between changes in demand and changes in supply by introducing a lag parameter that will offset inflation from the business cycle.

Interest rates

An interest rate reflects the cost of borrowing money.

In South Africa its central bank (the Reserve Bank) determines the base rate of interest, called the *bank rate*. Based on the bank rate and the cost of obtaining funds from their other sources (e.g. savings, investments and the money market), the banks then determine their rates of interest. The interest rate for a specific client or undertaking further depends on the bank's view of the risks involved and also the duration of the loan.

The Reserve Bank often uses the interest rate as a tool for controlling inflation in the economy. When the Reserve Bank expects inflation to rise, it may raise the interest rate in an attempt to reduce demand, thus slowing down the upward trend in inflation.

Forecasting interest rates will enable one to derive interest charges and certain incomes.

[Tennent J et al (2001)] again suggests the use of a sine curve model for the forecasting of interest rates. As there is a delay between the change in the interest rate and its effect on inflation, the interest rate can be offset against inflation. This offset can either be positive or negative, depending on whether the Reserve Bank acts in anticipation of or in reaction to changes in inflation.

Exchange rates

The exchange rate is the price at which two currencies exchange.

Exchange rates are very important in the analysis of capital projects as many factors can be derived from the exchange rate. The prices of products and the cost of imported goods and materials are often denominated in a foreign currency and the feasibility of such projects will therefore depend on the rate at which the local currency exchange to the specific foreign currency.

It is very difficult to forecast exchange rate movements as so many factors can determine the rates and also as some economies actively manage their exchange rates.

[Tennent J et al (2001)] describes the *purchasing power parity theory* of exchange rates, which argues that "… exchange rates move to ensure that the relative purchasing power of one currency against another remains constant …". This theory therefore implies that the exchange rates will move in response to the "… differential movements in the inflation rates between the respective economies …".

When applied to the Rand/ Dollar (R/$)-exchange rate, the purchasing power parity theory can be expressed as follows:

$$\Delta R = \frac{\Delta SA}{\Delta US}$$

where:

ΔR = The ratio of the R/$-exchange rate in one period to the rate in the preceding period. If R_t indicates the exchange rate at period t then $\Delta R = R_t / R_{t-1}$.

ΔSA = The ratio of the South African inflation rate in one period to the rate in the preceding period. If SA_t indicates the South African inflation rate at period t then $\Delta SA = SA_t / SA_{t-1}$.

ΔUS = The ratio of the US inflation rate in one period to the rate in the preceding period. If US_t indicates the US inflation rate at period t then $\Delta US = US_t / US_{t-1}$.

By applying this theory, the exchange rate in period *t* can therefore be expressed in terms of the exchange rate in the previous period (*t-1*) as follows:

$$R_t = R_{t-1} \times \frac{\left(\frac{SA_t}{SA_{t-1}}\right)}{\left(\frac{US_t}{US_{t-1}}\right)}$$

Therefore by forecasting the inflation rates of two respective countries, one can use the above expression to derive the exchange rates that are consistent with the purchasing power parity theory.

Population

Population is simply the number of people in a country. A detailed demographic analysis can produce a forecast.

Population is an important parameter as it is an indication of *market size*. Often a product's target market is expressed as a certain section or portion of the population, in which case the population forecast can be used to derive the size of the target market. Also, with the population and GDP forecasts one can calculate GDP per head, which is a useful indicator of individual wealth, which in turn can be an indicator for the *demand* of certain products and services.

Other Important Project Assumptions

In addition to the macroeconomic assumptions, the company must identify, research and estimate all the other parameters that will affect the feasibility of the project. Typical parameters to consider are:

- The cost of the capital items.
- Installation costs.
- Duration of installation.
- Working capital requirements.
- Incremental sales volumes.
- Prices.
- Cost Savings.
- Incremental expenses in respect of research and development, administration, production, labour, marketing, distribution, etc.
- Salvage values

The projections of these parameters must be realistic and consistent. Interrelationships and interdependencies must be identified and incorporated in the model.

Dealing with uncertainties

Given the long-term nature of capital projects, there will be a significant level of uncertainty regarding the values used for many of parameters.

The first step in dealing with these uncertainties is to identify all the parameters where *uncertainty* exists. The next step is to get an indication of each parameter's *impact*, which is an indication of how significantly the parameter influences the measure used in the model (e.g. net present value).

An efficient way to deal with such uncertainties is to identify and then to focus on those parameters with the highest degree of *uncertainty* and also the greatest *impact* on the business. [Tennent et al (2001)] suggests the use of the *impact/uncertainty matrix*, where all the parameters are categorized into four quadrants depending on whether the uncertainty and the impact are low or high. [Tennent et al (2001)] provides an example (see Table 23) of such a matrix as applied to the mobile business.

		IMPACT			
		Low		**High**	
UNCERTAINTY	**High**	Mobile browser technology Mobile encryption technology Billing costs E-commerce expenditure Speed of roll-out Billing system capabilities	Web-based servicing Fixed/mobile substitution Device availability Infrastructure availability Billing system costs Partnerships and joint ventures	Mobile-enabled machines Demand for video services Mobile video tariffs Number of competitors Type of competitors Advertising revenues	M-commerce expenditure Churn License fees Health issues Market share Mobile wallet Device subsidies Mobile data tariffs
	Low	Population growth Demographic trends Gross domestic product Income distribution Fixed-line penetration Leisure time Supplier contract terms	Content prices Internet penetration Customer to customer services agent ratio Cable penetration Broadband penetration Calling patterns	Mobile penetration Interconnect rates Interconnect income rates Fixed-line prices Staff availability Land area Worker mobility Accounting policies Tax rates Import duties Currency movements Data application	Regulatory environment Infrastructure costs Distribution channels Dealer commissions Capacity Roaming agreements Population density Price elasticity of demand Transaction commissions

Table 23: Impact/uncertainty matrix for a mobile business
[source: Tennent et al (2001)**]**

Uncertainty relates to the confidence the company has regarding the estimates of a parameter's future values.

Impact relates to the extent to which the parameter influences the measure used in the model. One way to get an indication of the impact of parameters is to examine the sensitivity of the model's outcome to variations in the parameters. Through *sensitivity analysis* one can identify those variables where additional information is required.

Depending on the size and significance of the project being analyzed, the impact/uncertainty matrix can be used as follows:

i) *High impact / high uncertainty*: Gather all internal and external information and intelligence available. Derive own estimates of how the variables will behave in future. Test these estimates with independent experts, if available.

ii) *High impact / low uncertainty*: Gather all internal and external information and intelligence available. Derive own estimates of how the variables will behave in future.

iii) *Low impact / high uncertainty*: Gather all internal and external information and intelligence available. Derive own estimates of how the variables will behave in future.

iv) *Low impact / low uncertainty*: Formulate best estimates of future behaviour.

If there is uncertainty regarding the value of a certain parameter, the best one can do is to *estimate* what the eventual value of the parameter will be. Being uncertain, the eventual value will probably lie in a certain range of values, with some values being more likely than others. In statistics, such an estimate is known as a *random variable*, which can best be described by means of a statistical probability distribution.

As described in section 2.4.5, the following three probability distributions can cater for most types of uncertainties: uniform distribution, normal distribution and the triangular distribution. Should the need arise to introduce any other distribution, the model can be modified to accommodate such other distributions.

3.4 Economic feasibility of projects

		Economic feasibility of projects
3.1	Portfolio theory and capital projects	The objectives of this section are as follows:
3.2	An integrated optimization model	• To explain why NPV was chosen as the decision criterion for economic feasibility.
3.3	Assumptions in the model	• To explain how the model deals with existing projects.
3.4	Economic feasibility of projects	• To describe what cash flows must be discounted in the calculation of the NPV.
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

3.4.1 Net present value (NPV) as the decision criterion

Having considered the merits of the various decision criteria in section 2.3, it was decided to use net present value (NPV) as the decision criterion for economic feasibility in the model. As explained in section 2.3.5, a project's NPV is an indication of the economic value that a project adds in present day terms. Also, the sum of the NPV's of a portfolio of projects is an indication of the economic value that the portfolio will add to the company, expressed in present day terms.

The discount rate in the NPV-calculation is usually equal to the sum of the risk-free rate, a profit margin and a risk margin that reflects the risks inherent in the project.

This model however determines the project and the portfolio risks explicitly through Monte Carlo simulation. As explained in section 2.4.5, it is not necessary to include a risk margin in the discount rate when the risks are determined explicitly. The discount rate used in this model is therefore equal to the risk-free rate plus a profit margin that can be the same for all the projects.

There is however still one short-coming of the NPV-method, namely the fact that the method of calculation implicitly assumes that all cash flows can be reinvested at a rate equal to the discount rate. There is a way of dealing with this and it can be considered in cases where the future reinvestment rates are markedly different form the discount rate. Instead of discounting the projected net cash flows at the discount rate, one firstly calculate a net future value by accumulating the cash flows at the future reinvestment rates (which differs from the discount rate) and then one determines an adjusted NPV by discounting this net future value at the discount rate.

3.4.2 The NPV of an existing project

The NPV-formula in section 2.3.5 usually applies to new projects. Since the model considers both new and existing projects, it is important to decide how to treat existing projects.

For an existing project, the model must indicate either whether to continue with the project or whether to terminate the project. It is therefore necessary to calculate both a *continuation value* and a *termination value*. Some companies also consider a "slow-down" option for existing projects. The 2003 annual report of Anglo Platinum for example reported on a thorough review of its project suite and the resultant decisions to slow down the implementation of a number of mining projects by between one and three years. If there are projects that can be slowed down, the model will require a "slow-down" value in addition to the continuation and the termination values.

The *continuation value* is simply the present value of the outstanding cash flows and the *termination value* is the value of all the net proceeds that can be raised on the termination of the project. The termination proceeds will be the net amount realized or incurred from the decision to terminate the project. It will include items such as:

i) Sale proceeds.

ii) If not sold, the value to the company of using the asset (whether plant or property) for other purposes (e.g. standby or other uses).

iii) The costs involved in canceling any contracts that are dependent on the continuation of the project.

iv) Labor costs.

v) Administration costs.

It is important to note that the project history is not taken into account when calculating the continuation value of an existing project. What happened in the past cannot be reversed and should therefore not impact the selection of the projects for the portfolio, as it is done on a "forward-looking" basis.

When one considers a project on its own, one would opt for termination of a project if its termination value exceeds the continuation value. In a portfolio context however, this is not necessarily the case. With constraints on capital availability and with the presence of other very attractive opportunities, the optimization model might terminate a project (whose continuation value exceeds its termination value) in order to release the capital that will enable the company to commence such other opportunities.

3.4.3 What cash flows to discount

In order to find the capital project portfolio that will maximize the value of the portfolio, the model requires the net cash flows for each of the new project candidates, the current projects and all those projects that can replace others as alternatives.

[Brealy et al, 1996] suggests the following three rules to apply when considering what cash flow items to include:

i) *Only cash flow is relevant.* Actual cash flows must be shown only when they are expected to occur. It is important not to confuse the determination of actual cash flows with accounting policies such as showing profit when earned as supposed to when the bills are actually paid. All non-cash items such as depreciation must be identified but must not be included.

ii) *Always state cash flows on an after-tax basis.* Some companies do not deduct tax and then offset this by discounting the before-tax cash flows using a higher discount rate. Even though it appears to be a simple approach, it can lead to wrong conclusions as different cash flows can have different impacts on taxation, e.g. [Johnson H, 1999]:

- Some cash flows have no impact on tax;
- Some are fully or partially taxable;
- Some are fully or partially tax-deductible.

The more accurate approach is therefore to analyze each cash flow in order to establish the correct tax treatment.

iii) *Always estimate cash flows on an incremental basis.* A very important principle in capital budgeting is the relevance of *incremental* cash flows. In order to reflect the impact that each project will have on the company, only the incremental cash flows, that show the net impact of each project on the overall cash flow stream of the company, are important. The term *differential* is also used in this context. An easy way to determine cash flows according to this principle is to assess the cash flows by comparing the overall cash flows on an "project-included" and "project-excluded" basis.

[Johnson H, 1999] suggests further that the cash flows must be aggregated to arrive at *net annual cash flows*. For each project one would then have the following cash flows:

- Cash flows at the time of acquisition (usually time zero);
- Annual cash flows for each year of the project's useful life;

- A final annual cash flow (including disposal-related cash flows) in the last year of the project's useful life.

The model must also accommodate projects that will not necessarily start at time zero. The company might be aware of a project that can only feasibly start at some future point in time and that will only require capital at that point. By including such projects as candidates, the model can take their impact on the portfolio into account. From a portfolio point of view, it might then be more attractive to exclude certain projects that can start right away in favour of a project that can only start at the future point in time.

The following cash flow components must be considered for each project:

- Cost
- Installation
- Working Capital
- Revenues
- Cost Savings
- Incremental Expenses
- Depreciation Tax Shield
- Salvage Value

[Johnson H, 1999] presented these items, their typical timings and the after-tax calculations as set out in Table 24.

TYPE	TYPICAL TIMING	AFTER-TAX CASH FLOW
Cost:		
Purchased (C)	0	-C
Transferred (OC)	0	-OC
Installation (INST)	0	-INST
Working Capital Changes (WC):		
Increase	0	-WC
Increase-reversal	*N*	WC
Decrease	0	WC
Decrease-reversal	*N*	-WC
Revenue (REV)	1 through *n*	REV(1-*t*)
Cost Savings (CS)	1 through *n*	CS(1-*t*)
Incremental Expense (EXP)	1 through *n*	EXP(1-*t*)
Depreciation Tax Shield (DTS_n)	1 through *n*	$(Dep_t)(t)$
Salvage Value:		
New Project (SV_n)	*N*	$SV_n + (BV_n - SV_n)(t)$
Existing Project (SV_E)	Varies	$-SV_E + (BV_E - SV_E)(t)$
Sale of existing project (MV_E)	0	$MV_E + (BV_E - MV_E)(t)$

Table 24: Capital Project Cash Flow Components

Cost

The first component in Table 24 is *cost*, which effectively represents the capital required for the project. *Cost* is usually incurred at the start of the project (at time zero), but is often staggered over the installation or construction period. At the time of acquisition there is no tax liability. The depreciation on the *cost* will have an impact on tax, as the depreciation amount reduces the company's tax liability over the depreciation period. Table 24 also makes a further distinction between *purchased* and *transferred* costs. *Purchased cost* refers to capital items that must be acquired from elsewhere, whereas *transferred cost* refers to capital items transferred to the project from inside the company. Such a transferred item has an *opportunity cost* (OC in Table 24), which is the cash that the item could have generated if it was sold or put to some other use in the company. [Johnson H, 1999] describes the opportunity cost of transferred equipment as "its value in the next best application".

Installation

It is normal practice to include the cost of installing the capital equipment in the capital amount that will then be depreciated over the same period as the purchase price of the equipment. The tax treatment of the installation cost is therefore similar to the actual cost of the equipment.

Working Capital

Working Capital is the difference between a company's short-term assets and liabilities. It is important to reflect the net impact that projects will have on cash flows related to such matters as accounts receivable and payable and inventories of raw material and finished goods. In order to estimate the impact of a project on working capital requirements, it is useful to analyze the "with or without the project" scenarios. Project analyses usually treat changes to net working capital as having 100% salvage values at the end of the project's life (as indicated in Table 24). As with cost and installation, there is no tax-impact associated with changes in net working capital.

Revenue

It is important to include revenue on an incremental basis (i.e. show increased revenue that will result from the project). Also, revenue will always be taxable, hence the net revenue of REV(1-t) in Table 24, where t is the applicable tax rate.

Cost Savings

Often capital projects result in higher productivity and efficiency that result in lower costs. Lower costs will result in higher profits and since profits are taxable, the cost savings must also be adjusted for tax, as shown in Table 24.

Incremental Expense

Capital projects often require additional expenses such as maintenance and labour. Since expenses are generally tax-deductible, the incremental expenses required for a capital project must also be adjusted for tax, as shown in Table 24. The impact of inflation must be incorporated in the projected values. Note that expense items can escalate at different rates.

Depreciation Tax Shield

Even though depreciation is a non-cash expense, it does reduce the taxable income and therefore adds to the project's net cash flow to the amount of (Dep)(t) (where "Dep" is the depreciation charge and t the tax rate), as shown in Table 24.

Salvage Value

The Salvage Value (SV) is the realizable value of plant and equipment once it has been completely used (i.e. the scrap value). If the Salvage Value (SV) exceeds the Book Value (BV) at that time, then there will be a tax liability of (SV-BV)(t). If the Book Value exceeds the Salvage Value the loss that will reduce the taxable gain that will result in a net taxable gain of (BV-SV)(t).

Consequential Benefits

Often the value of certain projects lies in their *consequential benefits*, that are the possibilities and opportunities that they create, which would otherwise not have been there had the projects not taken place. Given the long-term nature of capital projects, it is with a high degree of uncertainty that one would attempt to quantify the value of such benefits. As a result, companies usually opt for the conservative approach of ignoring these benefits. If it is possible to estimate the value of such consequential benefits, then such a value could be included in the project's final cash flow.

3.5 The multiple objective function

3.1	Portfolio theory and capital projects	***The multiple objective function*** The objectives of this section are to formulate and illustrate a measure that takes all the important objectives of the company into account for use as the objective function in the optimization program.
3.2	An integrated optimization model	
3.3	Assumptions in the model	
3.4	Economic feasibility of projects	
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

Background

In investment management, the objective is usually to *maximize the future value* of the assets in the portfolio, subject to certain rules and conditions. The same principle can be applied to a portfolio of capital projects, where the objective is the selection of the portfolio of projects that will maximize the *value to the company.*

In capital budgeting "value" is usually expressed in financial terms through the chosen decision criterion (e.g. payback period, net present value or internal rate of return). The fact that these decision criteria only express financial benefits, is a serious shortcoming. Companies also aim to achieve objectives other than just the financial rewards. These other objectives might be difficult to quantify, but their importance and value to the company are undoubtedly important.

It is proposed to develop an optimization model with a ***Multiple Objective Function (MOF)*** that maximizes the value in terms of the MOF, subject to all the constraints and other requirements.

A company's MOF is developed by:

- Identifying the multiple objectives.
- Attaching weights to the multiple objectives.
- Scoring all the existing and new projects per objective.
- Calculating each project's multiple objective score.
- Formulating the multiple objective function.

STEP 1: IDENTIFYING THE MULTIPLE OBJECTIVES

In addition to the very important objective of economics, companies also have other very important objectives such as: customer satisfaction, employee morale; health and safety; social responsibility; reputation in the market place; supplier relationships; service enhancement; environmental compliance; brand value; globalization; productivity; political relations and product quality. The company must identify the most important objectives as they relate to the choice of the company's capital projects. Most companies should be able to identify not more than say seven such key objectives.

To illustrate the use of multiple objectives, refer to the company Freesia Industries (see section 2.5.3) that identified the following five objectives as very important in respect of capital projects:

- economic feasibility
- health and safety
- customer satisfaction
- reputation in the market
- social responsibility.

STEP 2: ATTACHING WEIGHTS TO THE MULTIPLE OBJECTIVES

One can use the pairwise comparison procedure of the AHP (see Table 18) to determine the objectives' relative importance. The outcome of these pairwise comparisons will be the weights for the objectives:

> Objective weights: $\omega_1, \omega_2, \omega_3, \ldots \omega_n$, such that $\sum_{j=1}^{n} \omega_j = 1$,
>
> where n = number of objectives.

The weights of the five objectives for Freesia Industries are shown in Table 25.

Objective	Weight
Economic feasibility	60%
Health and safety	20%
Customer satisfaction	10%
Reputation in the market	6%
Social responsibility	4%

Table 25: Weights in terms of importance of the objectives for Freesia Industries

These weights are indicators of relative importance in terms of value to the company. One way to interpret the weights is to say that "economic feasibility" is three times as important as "health and safety", which again is twice as important as "customer satisfaction" in respect of capital budgeting.

STEP 3: SCORING OF PROJECTS PER EACH OBJECTIVE

Once the relative importance of the multiple objectives have been determined, the next step will be to score each of the projects on each of the objectives, such that:

s_{ij} = score of project i i.r.o. objective j,

where:

$i = 1,2,\ldots, m$ - the number of projects

$j = 1,2,\ldots,n$ - the number of objectives

$$\text{and } \sum_{i=1}^{m} s_{ij} = 1$$

Table 20 illustrates how the scoring for the projects can be done when it is possible to determine a tangible value for each project in respect of a specific objective (e.g. NPV in respect of "economic feasibility").

When the objectives are intangible, it becomes more difficult to score the projects. The pairwise comparison method of the AHP can be used for this purpose (see Table 26 for the derivation of the project scores for the projects in the Freesia Industries illustration, in respect of "reputation in the market").

	A	B	C	D	E	F	G	H	I
1	**AHP Work Sheet**								
2									
3	**Level 1**	**TOPIC**	Reputation in market						
4	**Level 2**	**FACTORS**	Project A	Project B	Project C	Project D	Project E	Project F	
5									
6	**Size of Criteria Matrix =**	6							
7									
8	**Factors Matrix**								
9									
10	**Reputation in market**	Project A	Project B	Project C	Project D	Project E	Project F		
11	Project A	1.00	6.00	2.00	4.00	6.00	5.00		
12	Project B	0.17	1.00	0.33	0.67	1.00	1.00		
13	Project C	0.50	3.00	1.00	1.50	3.50	3.50		
14	Project D	0.25	1.50	0.67	1.00	1.50	1.40		
15	Project E	0.17	1.00	0.29	0.67	1.00	1.00		
16	Project F	0.20	1.00	0.29	0.71	1.00	1.00		
17		2.28	13.50	4.57	8.55	14.00	12.90		
18									
19	**Normalized Factors Matrix**	Project A	Project B	Project C	Project D	Project E	Project F	**Priority Vector**	
20	Project A	0.44	0.44	0.44	0.47	0.43	0.39	43%	
21	Project B	0.07	0.07	0.07	0.08	0.07	0.08	7%	
22	Project C	0.22	0.22	0.22	0.18	0.25	0.27	23%	
23	Project D	0.11	0.11	0.15	0.12	0.11	0.11	12%	
24	Project E	0.07	0.07	0.06	0.08	0.07	0.08	7%	
25	Project F	0.09	0.07	0.06	0.08	0.07	0.08	8%	
26		1.00	1.00	1.00	1.00	1.00	1.00	1.00	
27									
28	**Consistency Check**								
29		0.43	0.45	0.45	0.47	0.44	0.38	2.62	6.03
30		0.07	0.07	0.08	0.08	0.07	0.08	0.45	6.02
31		0.22	0.22	0.23	0.17	0.25	0.27	1.36	6.02
32		0.11	0.11	0.15	0.12	0.11	0.11	0.70	6.04
33		0.07	0.07	0.06	0.08	0.07	0.08	0.44	6.02
34		0.09	0.07	0.06	0.08	0.07	0.08	0.46	6.02
35								**lambda max =**	6.02
36								**Consistency Index =**	1.25%
37								**Consistency Ratio =**	1.0%
38								**Consistency Result =**	**Good**

<u>Table 26:</u> Pairwise comparison derivation (using a spreadsheet) of the project scores for Freesia Industries in respect of "reputation in market"

The pairwise comparison method produces consistent answers, but a criticism is that the exercise can quickly become cumbersome as the number of projects increases.

An alternative way of dealing with many projects is to rate each project on a comparative scale in terms of each objective and to weigh the results as was done in Table 20 for the tangible NPV. Table 27 illustrates how this was done for the "reputation in market" - objective.

Comparative rating

Objective: Reputation in market

Rating	Interpretation
1	Lowest score for objective
2	
3	Intermediate comparative scores for objective.
4	
5	Highest score for objective

	Rating	Weight
Project A	5	38%
Project B	1	8%
Project C	3	23%
Project D	2	15%
Project E	1	8%
Project F	1	8%
	13	100%

Table 27: Determination of project scores with a comparative rating method.

Although not exactly the same, the project scores derived from Table 27 (where only 6 ratings were required) are very similar to the results of the pairwise comparison in Table 26 (where 15 pairwise comparisons had to be done). If a company had to consider 30 projects, then the comparative rating method will require 30 ratings, whereas the pairwise comparison approach will require 435 comparisons per objective!

STEP 4: CALCULATING EACH PROJECT'S MULTIPLE OBJECTIVE SCORE

A project's multiple objective score is its weighted average score where the score for each objective is weighed by the objective's weight.

$$S_i = \sum_{j=1}^{n} \omega_j s_{ij}$$

where:

S_i = The multiple objective score of project i.

ζ_j = The relative importance weight for objective j.

s_{ij} = Score of project i in respect of objective j.

n = Number of objectives.

Table 21 illustrates how the multiple objective score for each of the Freesia Industries projects is calculated as:

Project	Multiple objective score
A	22.32
B	16.34
C	19.37
D	15.03
E	12.76
F	14.19

The above scores must be interpreted as relative indicators of value to the company. There is no unit for these scores, except that they indicate relative value in terms of the company's multiple objectives. One could for example state that Project A is 75% more "valuable" than Project E in terms of the company's multiple objectives, calculated as follows:

$$\left(\frac{Score\ Project\ A}{Score\ Project\ B} - 1\right) = \left(\frac{22.32}{12.76} - 1\right) = 74.92\%$$

STEP 5: FORMULATING *MOF*, THE MULTIPLE OBJECTIVE FUNCTION

A company's multiple objective function can be formulated as follows:

$$MOF = \sum_{i=1}^{m} S_i x_i$$

where:

- MOF = The company's multiple objective function for its portfolio of capital projects.
- S_i = The multiple objective score for project i.
- x_i = The decision variable for project i, such that $x_i = 1$ means that the project is selected for the portfolio and $x_i = 0$ means that the project is not selected.
- m = Number of projects.

The MOF will be the objective function of the optimization program, such that the optimal portfolio of projects is the one that maximizes the value of the MOF.

In the case of Freesia Industries, the MOF can be written as follows:

$$\boldsymbol{MOF = 22.32x_A + 16.34x_B + 19.37x_C + 15.03x_D + 12.76x_E + 14.19x_F}$$

3.6 Risk analysis of projects

Risk in respect of capital projects is defined as *the probability that the project will make a loss*.

The model uses the net present value (NPV) as the decision criterion for economic feasibility with a discount rate equal to the risk-free rate plus a profit margin. The discount rate for NPV often includes a risk margin, but it was decided not to follow that route and to rather determine the project's risk explicitly with Monte Carlo simulation. By following this procedure, "risk" therefore translates to *the probability of a negative NPV*. In section 2.4.5 the project risk for the Electric Scooter project was calculated as 28% (see Figure 12). In other words there is a probability of 28% that the Electric Scooter project will make a loss.

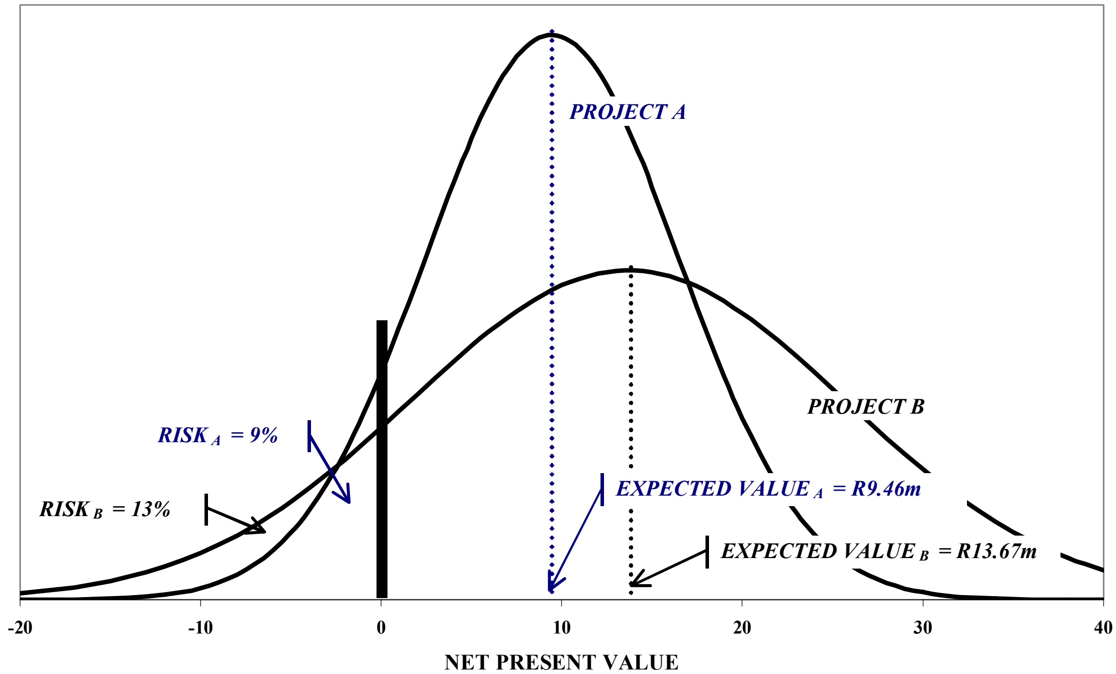
The company should specify its own *risk threshold*, which can be expressed as a maximum acceptable project risk. In its screening of new projects, the company can then determine each project's risk and can decline all those projects where the risk exceeds the risk threshold. For example, if the company's project risk threshold were 20%, it would decline the Electric Scooter project that has a project risk of 28%.

Various factors will determine a company's attitude towards risk. Such factors include:

- Financial capacity: The bigger the company's financial capacity the more able it is to absorb the risks inherent in the more risky projects.
- Track record: If the company has a successful track record with similar projects, it might be more able to manage inherent risks.
- Expertise: The higher the company's level of expertise (both technical and managerial), the higher the company's ability to manage project risks.
- Industry: Attitudes towards risk might vary from one industry to another.
- Capital requirement: The amount of capital that has to be committed to the project can also influence the company's attitude towards risk. The more capital required, the more cautious companies tend to be.
- Pay-off: The level of potential project pay-off might also influence the company's stance on risk-taking. Some pay-off might just be so attractive that the company is willing to compromise on its attitude towards risk.

The additional information provided by the project risk analysis, is very useful in the decision-making process. For example, a company with a risk threshold of 10% might be in a position to select between projects A and B:

	Project A	**Project B**
Expected NPV	R9.46m	R13.67m
Standard Deviation	R7m	R12m
Risk (Probability of a negative NPV)	9%	13%



<u>Figure 16:</u> Probability distributions of the NPV's of projects A and B

Even though the expected NPV of Project B (R13.67m) is significantly higher than Project A (R9.46m), it has a higher probability (13% as supposed to 9%) of not yielding the returns that are demanded by the investors. According to the company's risk threshold of 10%, it should select Project A, but given the above results, the company might reconsider.

3.7 Risk analysis of the portfolio of projects

3.1	Portfolio theory and capital projects	***Risk analysis of the portfolio of projects*** The objective of this section is to propose two methods whereby one can calculate the risk of the portfolio of projects.
3.2	An integrated optimization model	
3.3	Assumptions in the model	
3.4	Economic feasibility of projects	
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

In order to select an optimal portfolio of projects, one must be able to calculate *the risk for the portfolio as a whole*, as it is important for the company to ensure that the overall portfolio risk lies within acceptable limits. Similar to the definition of project risk, the portfolio risk can be defined as the probability of a negative NPV of the portfolio of projects.

Diversification in a portfolio

A diversified portfolio of capital projects is one that is made up of individual projects whose performances will vary under different circumstances. In certain circumstances, some projects will yield excellent returns while others might be struggling. In a diversified portfolio it therefore often happens that the excellent performance by some projects is often offset by the poorer performance of others and vice versa.

While the return on the portfolio will be equal to the weighted average return of the projects in the portfolio, the standard deviation of the portfolio will be less than the weighted average standard deviation of the projects in the portfolio. Brealy et al states that *"... even a little diversification can provide a substantial reduction in variability ..."* and then illustrates the effect of diversification on the portfolio standard deviation as in Figure 17.

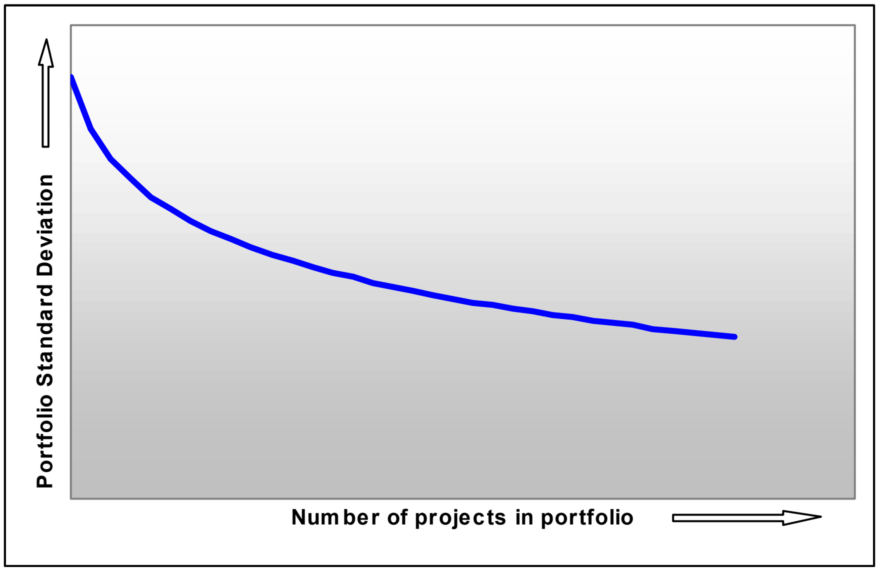


Figure 17: Diversification reduces risk rapidly at first, then more slowly (Brealy et al)

The portfolio risk consists of the following two components (shown in Figure 18):

- *Unique risk* is that component of the portfolio risk that can be eliminated by diversification and it stems from the unique circumstances of the company.
- *Market risk* represents those risks that cannot be eliminated by diversification and stems from the many risks that companies face (e.g. economic, political, etc.).

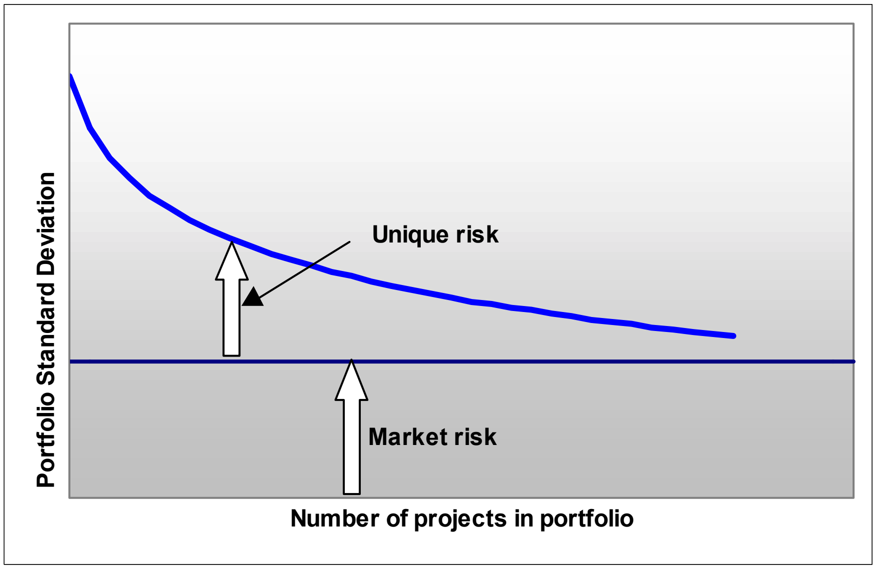


Figure 18: Diversification can reduce *unique risk* but cannot eliminate *market risk*. (Brealy et al)

Calculating Portfolio Risk

The formula below is based on the way that *Brealy et al* calculates the variance of a portfolio of securities:

$$Portfolio\ Variance = \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j \rho_{ij} \sigma_i \sigma_j$$

where:

N = The number of projects in the portfolio

x_i, x_j = The proportion of the portfolio NPV represented by NPV's of the projects *i* and *j*, where $i, j = 1, 2, 3, \ldots, N$.

ρ_{ij} = Correlation coefficient between projects *i* and *j*.

σ_i , σ_j = The standard deviations of projects *i* and *j*.

The *correlation coefficient* between two variables is a description of the relationship between the two variables. The correlation coefficient has the following two important aspects:

- Its sign (positive or negative) indicates the direction of the relationship. A *positive* sign indicates a *direct* relationship, in which case both variables tend to move in the same direction as circumstances change. A *negative* sign indicates an *inverse* relationship, in which case the variables tend to move in opposite directions as circumstances change.
- The absolute value of the correlation coefficient indicates the extent of the relationship (the higher the absolute value, the stronger the relationship).

When applying the portfolio variance formula to a portfolio that consists of only three projects, the portfolio variance will be equal to the sum of the expressions in the nine boxes below.

	Project 1	**Project 2**	**Project 3**
Project 1	$x_1^2\sigma_1^2$	$x_1x_2\rho_{12}\sigma_1\sigma_2$	$x_1x_3\rho_{13}\sigma_1\sigma_3$
Project 2	$x_1x_2\rho_{12}\sigma_1\sigma_2$	$x_2^2\sigma_2^2$	$x_2x_3\rho_{23}\sigma_2\sigma_3$
Project 3	$x_1x_3\rho_{13}\sigma_1\sigma_3$	$x_2x_3\rho_{23}\sigma_2\sigma_3$	$x_3^2\sigma_3^2$

In investment portfolio management the correlation coefficients between the different investments are derived from historic price movements. In a portfolio of capital projects one does not have a performance history of the various projects, but rather models that project future cash flows. It is suggested that one use the *Monte Carlo* simulation technique in order to calculate the correlation coefficients required by the portfolio variance formula. However in order to determine the correlation coefficients, it is necessary to simulate all the projects in the same simulation, thereby effectively creating a large number of different scenarios of the future. This enables one to examine the outcome of each project under different scenarios and to calculate the correlation between the projects.

The output of the Monte Carlo simulation will be the project results obtained from the simulated future environments. It is then easy to calculate the following values:

- The expected future value for each project.
- The standard deviation for each project.
- The correlation coefficient for each pair of projects.

Given these values one can apply the portfolio variance formula to calculate the portfolio variance. One now has the portfolio's expected value and its variance. The portfolio risk will be determined by calculating the probability that the portfolio's NPV will be negative.

Calculating the portfolio risk using the normal distribution

One approach is to assume that the portfolio's NPV has a normal distribution with the following parameters:

λ = the expected total NPV of the portfolio.

ρ = the standard deviation of the portfolio's NPV.

By applying the cumulative distribution formula of the normal distribution, it is then easy to determine the portfolio risk as the probability that the NPV will be negative. By using the normal distribution formula, one can structure the model in such a way that the risk of the selected portfolio does not exceed a specific level.

Calculating portfolio risk if the normal distribution is inappropriate

By performing a Monte Carlo simulation on the selected portfolio, the results can be presented in a histogram and one can then judge whether or not the shape of the distribution reflects the normal distribution. If it is clear that the normal distribution is the wrong assumption, then one can use the results of the Monte Carlo simulation to estimate the portfolio risk as follows:

$$Portfolio\ risk = \frac{Number\ of\ negatve\ Monte\ Carlo\ outcomes}{Total\ number\ of\ Monte\ Carlo\ runs}$$

One can structure the model in such a way that the selection of projects is such that the portfolio risk does not exceed a defined limit that represents the company's attitude towards risk-taking.

3.8 Constraints

<table>
<tr><td>3.1</td><td>Portfolio theory and capital projects</td><td rowspan="10">Constraints

The objectives of this section are:
• to describe the main constraints for the model and
• to illustrate how to allow for special relationships amongst projects.</td></tr>
<tr><td>3.2</td><td>An integrated optimization model</td></tr>
<tr><td>3.3</td><td>Assumptions in the model</td></tr>
<tr><td>3.4</td><td>Economic feasibility of projects</td></tr>
<tr><td>3.5</td><td>The multiple objective function</td></tr>
<tr><td>3.6</td><td>Risk analysis of projects</td></tr>
<tr><td>3.7</td><td>Risk analysis of the portfolio of projects</td></tr>
<tr><td>3.8</td><td>Constraints</td></tr>
<tr><td>3.9</td><td>The optimal solution</td></tr>
<tr><td>3.10</td><td>Portfolio management</td></tr>
</table>

It is important that the model's solution is realistic and that the company is in fact able to implement the model's recommendations. It is for this reason that the correct formulation of the constraints and project interrelationships in the model is imperative. This is where the environment within which the portfolio must perform and all the rules that the portfolio must adhere to, are defined.

Constraints

Hence the needs to carefully specify the constraints in terms of the various factors of production, such as materials, floor space, machine times and labour. One of the most important constraints in capital budgeting is capital availability, which must be stated for each year. One can extend the model to incorporate constraints on certain critical factors of production such as:

- the availability of raw materials;
- production limits of machinery and plants;
- limitations on access to skilled labour;
- limited storage space;
- distribution constraints, etc.

Therefore, when two or more projects compete for the same resources, the model will not select projects whose collective demand for certain resources exceed the availability of such resources.

Special Project Interrelationships

There are always a number of conditions and relationships between projects that must apply and that must therefore be considered in the composition of the capital project portfolio. It is important to identify all such conditions and interrelationships and to clearly specify them as constraints in the model. Herewith a number of typical relationships (most described by [Wilkes *et al* (1978)]).

One, but not both:

For the two projects *j* and *k* with the decision variables x_j and x_k (where x_j and $x_k = 0 \text{ or } 1$), the following relationship will ensure that one, but not both will be included in the portfolio:

$$x_j + x_k = 1$$

The table shows all the allowable combinations and the interpretations of this constraint:

x_j	x_k	**Interpretation**
1	0	Project *j* to be included, but not project *k*.
0	1	Project *k* to be included, but not project *j*.

One or neither, but not both:

For the two projects *j* and *k* with the decision variables x_j and x_k (where x_j and $x_k = 0 \text{ or } 1$), the following relationship will ensure that one or neither of the two projects, but not both will be included in the portfolio:

$$x_j + x_k \leq 1$$

The table shows all the allowable combinations and the interpretations of this constraint:

x_j	x_k	**Interpretation**
0	0	Neither of projects *j* or *k* to be included.
1	0	Project *j* to be included, but not project *k*.
0	1	Project *k* to be included, but not project *j*.

Project k only if project j is included:

For the two projects *j* and *k* with the decision variables x_j and x_k (where x_j and $x_k = 0 \text{ or } 1$), the following relationship will ensure that project *k* will only be considered for inclusion if project *j* has been included in the portfolio:

$$x_j - x_k \geq 0$$

The table shows all the allowable combinations and the interpretations of this constraint:

x_j	x_k	Interpretation
0	0	Neither of projects *j* or *k* to be included.
1	0	Project *j* to be included, but not project *k*.
1	1	Project *j* to be included, and also project *k*.

In other words, project *k* cannot be included ($x_k = 1$) when project *j* is excluded ($x_j = 0$), as it will violate the constraint.

One of or both:

For the two projects *j* and *k* with the decision variables x_j and x_k (where x_j and $x_k = 0 \text{ or } 1$), the following relationship will ensure that either at least one of the projects or both will be included in the portfolio:

$$x_j + x_k \geq 1$$

The table shows all the allowable combinations and the interpretations of this constraint:

x_j	x_k	Interpretation
1	0	Project *j* to be included, but not project *k*.
0	1	Project *k* to be included, but not project *j*.
1	1	Project *j* to be included, and also project *k*.

Both or neither:

For the two projects *j* and *k* with the decision variables x_j and x_k (where x_j and $x_k = 0 \text{ or } 1$), the following relationship will ensure that either both or neither of the two projects will be included in the portfolio:

$$x_j = x_k$$

The table shows all the allowable combinations and the interpretations of this constraint:

x_j	x_k	**Interpretation**
0	0	Both projects *j* and *k* not included.
1	1	Both projects *j* and *k* included.

Any two of three projects:

For the three projects *j, k* and *l*, with the decision variables x_j, x_k and x_l (where x_j, x_k and $x_l = 0 \text{ or } 1$), the following relationship will ensure that any two of the projects will be included in the portfolio:

$$x_j + x_k + x_l = 2$$

The table shows all the allowable combinations and the interpretations of this constraint:

X_j	x_k	x_l	**Interpretation**
1	1	0	The **two** projects *j* and *k* included, but *l* excluded.
1	0	1	The **two** projects *j* and *l* included, but *k* excluded.
0	1	1	The **two** projects *k* and *l* included, but *j* excluded.

Limit on the number of projects:

The following constraint will ensure that the number of projects (selected from *m* possible candidates) will not exceed a specified limit, *n*:

$$\sum_{j=1}^{m} x_j \leq n$$

3.9 The optimal solution

3.1	Portfolio theory and capital projects	***The optimal solution*** The objective of this section is to give a brief description of the optimization software used in the model.
3.2	An integrated optimization model	
3.3	Assumptions in the model	
3.4	Economic feasibility of projects	
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

It was decided to use the What'sBest optimization software (developed by Lindo Systems, Inc.). This software can be installed as an Add-in in an Excel spreadsheet. In this way, the Excel becomes a solver capable of performing linear, integer and nonlinear optimization on the most difficult problems. The fact that What'sBest was used for this dissertation does not imply that it is the best optimization software program, as there are other available, such as Excel's own Solver.

In What'sBest it is very easy to set up the following components of the model:

- The model's <u>decision variables</u> are set up as the "adjustable cells", as these are the cells that What'sBest can adjust in its search for the optimal solution. One can restrict certain cells to being integers.
- The model's <u>objective function</u> is denoted the "Best" cell. In the capital project model, this cell will contain the multiple objective function (MOF) which must be maximized.
- The third component is the model's <u>constraints</u>.

Once the model is set up, What'sBest very quickly provides the optimal solution. It also produces a detailed report with the solver statistics.

3.10 Portfolio management

3.1	Portfolio theory and capital projects	***Portfolio management*** The objective of this section is to describe the role of the model in the management of the company's portfolio of capital projects.
3.2	An integrated optimization model	
3.3	Assumptions in the model	
3.4	Economic feasibility of projects	
3.5	The multiple objective function	
3.6	Risk analysis of projects	
3.7	Risk analysis of the portfolio of projects	
3.8	Constraints	
3.9	The optimal solution	
3.10	Portfolio management	

Once the optimal solution has been implemented, it requires management on a continual basis in order to remain optimal. If the model is maintained, it can be re-run in order to indicate whether changes to the portfolio are necessary in events such as:

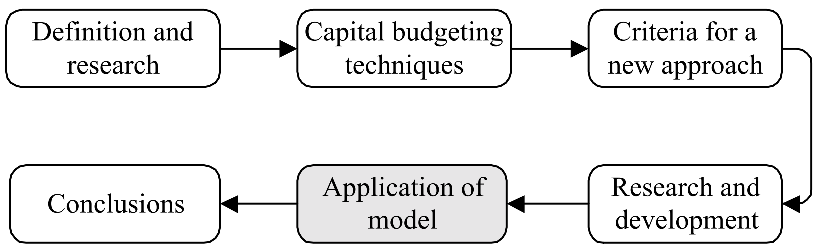
- changes to the company's strategy;
- changes in the economy;
- changes in the industry;
- changes in legislation;
- the identification of new opportunities;
- changes regarding the level of uncertainty regarding certain assumptions;
- project outcomes that might differ from the original projections;
- changes in any of the constraints.

By using the model in this way, the company will benefit from the quick processing of the new information in an integrated business model.

APPLICATION OF THE PORTFOLIO APPROACH TO CAPITAL PROJECT MANAGEMENT

4.1 Background and objective

The objective of this chapter is to illustrate the application of the approach as described in the previous chapter, to a hypothetical case. Figure 19 highlights this objective in relation to the overall approach for the dissertation.



<u>Figure 19:</u> The objective of chapter 4 in relation to the overall approach for the dissertation.

Freesia Industries is the hypothetical company in this application. The company's products are priced in US$ and some capital costs and expenses are also US$-based, whereas others are Rand-based. The company currently manages nine capital projects and has identified a further seven for consideration (see Table 28).

EXISTING PROJECTS	NEW PROJECTS
Namaqua	Euroshaft
Landmax	Aston
Brakflow	Ultra
Fourport	Sabie
Extrema	Hertz
LevelOne	Bank
Hever	Discover
Castle	
Kwasand	

Table 28: The projects that Freesia Industries can select from.

The objective for the company is to find the optimal portfolio of projects that does not only take economics into account, but that also considers the other important company objectives and constraints.

This chapter will demonstrate the following:

- **Section 4.2** describes the identification and the allocation of weights to the company's *multiple objectives*.
- **Section 4.3** defines and describes the company's *macroeconomic assumptions*.
- **Section 4.4** analyzes the *economic feasibility and risk* of each of the projects.
- **Section 4.5** illustrates how to score each project in terms of the company's multiple objectives and how to formulate the company's *multiple objective function* for this investigation.
- **Section 4.6** describes the *constraints* and the logical *project interrelationships* that the optimal portfolio must adhere to.
- **Section 4.7** describes how to find the optimal portfolio of capital projects for the company.
- **Section 4.8** compares the net present value (NPV) to the multiple objective function (MOF) as the objective function for the optimization program.
- **Section 4.9** shows how to determine the risk profile of the portfolio of projects.

- **Section 4.10** describes how the model can be used to manage the portfolio of projects after implementation.
- **Section 4.11** concludes the chapter with some observations and remarks.

4.2 The company's multiple objectives

Freesia Industries decided to find the optimal portfolio of capital projects that will maximize adherence to the following multiple objectives:

- Economic feasibility.
- Health and safety.
- Customer satisfaction.
- Reputation in the market.
- Social responsibility.

In order to determine the relative importance of these multiple objectives, it was decided to use the pairwise comparison technique, as described in the Analytical Hierarchy Process (AHP). Section 2.5.3 described and illustrated this technique, as applied to Freesia Industries. Table 29 shows the relative importance of these objectives.

Objective	Weight
Economic feasibility	60%
Health and safety	20%
Customer satisfaction	10%
Reputation in the market	6%
Social responsibility	4%

Table 29: Relative importance of Freesia Industries multiple objectives.

4.3 The company's macroeconomic assumptions

Freesia Industries decided to incorporate the macroeconomic model described in section 3.3.

Since the company trades internationally, mainly with the USA, the model has to forecast the following macroeconomic parameters:

- The *Gross Domestic Product (GDP)* of South Africa. The growth rate in the GDP is an indication of the country's business cycle and can be used to derive estimates for the demand of the company's products. Since the macroeconomic parameters are interdependent, the GDP can also be used to estimate other parameters such as inflation and the exchange rate.
- The *Gross Domestic Product (GDP)* of the USA. The GDP growth rate in the USA can be used to estimate the demand for the company's product in the USA. The GDP can also be used to estimate the inflation rate in the USA.
- The *inflation rate* in South Africa. The inflation rate is used to estimate increases in expenses and is also used to estimate future R/$-exchange rates.
- The *inflation rate* in the USA. The USA inflation rate is required in the model to derive the R/$-exchange rate.
- The *R/$-exchange rate*. Since the products are priced in $ and since certain costs are also expressed in $-terms, one needs the exchange rate to convert all the currencies to Rand.

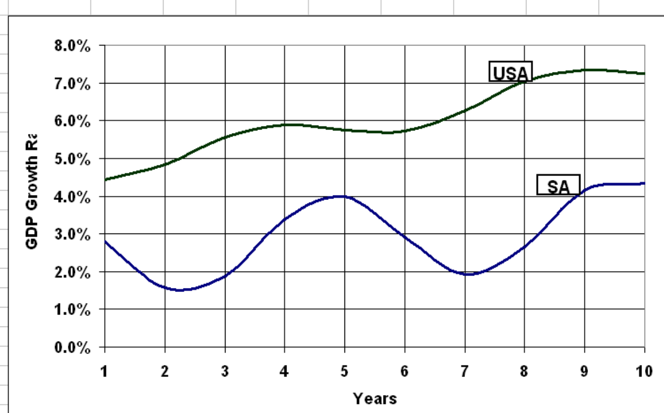
Freesia Industries decided to incorporate the macroeconomic model described in section 3.3. This model ensures that the projections of these parameters are consistent throughout. For example, as the exchange rate model is based on the purchasing power parity theory, changes in the respective inflation rates will produce an exchange rate that is consistent with the assumed theory.

Following the modeling approach described by Tennent et al (2001), Table 30 shows all the assumptions and calculations done for the projection of the South

African and the USA GDP growth rates. Table 30 also provides a graphical presentation of the corresponding projected GDP growth rates of the two countries.

Note how the model in Table 30 provides for the specification and description of uncertainties regarding certain assumptions. An example is the length of the business cycle in South Africa, which Table 30 describes as a triangular distribution with 4, 5 and 7 years as the minimum, most likely and the maximum cycle lengths respectively. By setting up the model in this way, it is easy to perform Monte Carlo simulations where values are generated from these probability distributions for the successive simulation runs.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Macroeconomic assumptions**											
2												
3	**Description of uncertainties in assumptions:**											
4												
5			Distr.	P1	P2	Random	Estimate					
6	GDP(SA):											
7	Cycle length (yrs)	5	T	4	7	0.1968	4.8					
8	Amplitude	2.0%	T	0.5%	3.0%	0.819	2.3%					
9	Average GDP growth rate trend	2.0%	N	2.0%	1.0%	0.923	3.4%					
12	GDP(USA):											
13	Cycle length (yrs)	5	U	4.5	5.5	0.347	4.8					
14	Amplitude	1.0%	N	1.0%	0.2%	0.124	0.8%					
15	Average GDP growth rate trend	4.0%	N	4.0%	1.0%	0.820	4.9%					
18												
19	**Calculations and projections:**											
20												
21	**GDP(SA)**											
22												
23	GDP	10,000										
24	Cycle length (yrs)	4.8										
25	Cycle starting point	25%										
26	Amplitude	2.33%										
27	Average GDP growth rate	2.50%										
28	Average growth rate trend	3.43%										
29												
30			1	2	3	4	5	6	7	8	9	10
31	Cycle point increment		21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%
32	Cycle point		46%	67%	88%	9%	30%	51%	72%	93%	14%	35%
33	Sine curve position		25.0%	-87.5%	-68.8%	53.0%	95.4%	-5.2%	-98.0%	-43.9%	76.0%	82.0%
34	Half of amplitude		1.16%	1.16%	1.16%	1.16%	1.16%	1.16%	1.16%	1.16%	1.16%	1.16%
35	Adjusted growth rate		2.500%	2.586%	2.674%	2.766%	2.861%	2.959%	3.060%	3.165%	3.274%	3.386%
36												
37	GDP growth rate		2.800%	1.570%	1.880%	3.390%	3.980%	2.900%	1.930%	2.660%	4.160%	4.340%
38	GDP forecast		10,280	10,441	10,638	10,998	11,436	11,768	11,995	12,314	12,826	13,383
39												
57	**GDP(USA)**											
58												
59	GDP	10,000										
60	Cycle length (yrs)	4.8										
61	Cycle starting point	50%										
62	Amplitude	0.77%										
63	Average GDP growth rate	4.80%										
64	Average growth rate trend	4.92%										
65												
66			1	2	3	4	5	6	7	8	9	10
67	Cycle point increment		20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%	20.6%
68	Cycle point		71%	91%	12%	33%	53%	74%	94%	15%	36%	56%
69	Sine curve position		-96.3%	-52.2%	68.0%	89.0%	-19.7%	-99.7%	-34.3%	81.1%	78.3%	-38.7%
70	Half of amplitude		0.38%	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%	0.38%
71	Adjusted growth rate		4.800%	5.036%	5.284%	5.543%	5.816%	6.102%	6.402%	6.717%	7.047%	7.393%
72												
73	GDP growth rate		4.430%	4.840%	5.550%	5.890%	5.740%	5.720%	6.270%	7.030%	7.350%	7.250%
74	GDP forecast		10,443	10,948	11,556	12,237	12,939	13,679	14,537	15,559	16,702	17,913
75												



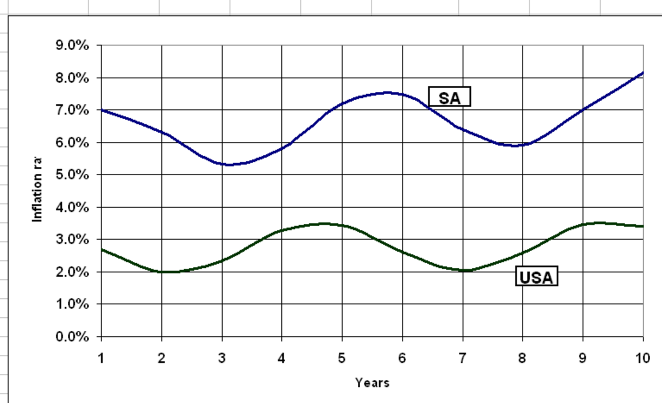
<u>Table 30:</u> Assumptions and calculations for the GDP growth rate projections.

Table 31 shows the assumptions and calculations for the respective inflation rates. This model links the inflation rate cycles to the business cycles with the parameter called "Offset to GDP growth".

Table 31 also shows the exchange rate projections, based on the respective inflation rates and the application of the purchasing power parity theory.

It is important that the company is satisfied with the projected macroeconomic variables. If the macroeconomic model does not provide realistic values, the assumptions of the model must be revised or the model should accommodate manual inputs that can override the values generated by the model.

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Macroeconomic assumptions**											
2												
3	**Description of uncertainties in assumptions:**											
4												
5			**Distr.**	**P1**	**P2**	**Random**	**Estimate**					
10	**Inflation (SA):**											
11	Inflation Rate Trend	2.0%	T	1%	4%	0.090	1.52%					
16	**Inflation (USA):**											
17	Inflation Rate Trend	0.5%	U	0.4%	0.6%	0.951	0.59%					
18												
19	**Calculations and projections:**											
20												
40	**Inflation (SA)**											
41												
42	Index Start Point	100										
43	Average Inflation Rate	6.00%										
44	Total Amplitude	2.00%										
45	Offset to GDP growth	1										
46	Inflation Rate Trend	2.00%										
47			1	2	3	4	5	6	7	8	9	10
48	Cycle Point Increment		21.8%	21.8%	21.8%	21.8%	21.8%	21.8%	21.8%	21.8%	21.8%	21.8%
49	Cycle Point		25.00%	47%	69%	90%	12%	34%	56%	78%	99%	21%
50	SINE curve position		100.0%	20.0%	-92.0%	-56.7%	69.4%	84.4%	-35.7%	-98.6%	-3.6%	97.2%
51	Half of amplitude		1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
52	Adjusted Growth Rate		6.000%	6.120%	6.242%	6.367%	6.495%	6.624%	6.757%	6.892%	7.030%	7.171%
53												
54	Inflation Rate		**7.00%**	**6.32%**	**5.33%**	**5.81%**	**7.19%**	**7.47%**	**6.40%**	**5.91%**	**7.00%**	**8.15%**
55	Inflation Index		107.0	113.8	119.8	126.8	135.9	146.1	155.4	164.6	176.1	190.5
56												
76	**Inflation (USA)**											
77												
78	Index Start Point	100										
79	Average Inflation Rate	2.70%										
80	Total Amplitude	1.50%										
81	Offset to GDP growth	1										
82	Inflation Rate Trend	0.59%										
83			1	2	3	4	5	6	7	8	9	10
84	Cycle Point Increment		20.7%	20.7%	20.7%	20.7%	20.7%	20.7%	20.7%	20.7%	20.7%	20.7%
85	Cycle Point		50%	71%	91%	12%	33%	54%	74%	95%	16%	36%
86	SINE curve position		0.0%	-96.4%	-51.4%	69.0%	88.1%	-22.1%	-99.9%	-31.2%	83.3%	75.5%
87	Half of amplitude		0.75%	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%	0.75%
88	Adjusted Growth Rate		2.700%	2.716%	2.732%	2.748%	2.764%	2.781%	2.797%	2.814%	2.830%	2.847%
89												
90	Inflation Rate		**2.70%**	**2.00%**	**2.35%**	**3.27%**	**3.43%**	**2.62%**	**2.05%**	**2.58%**	**3.46%**	**3.42%**
91	Inflation Index		102.7	104.8	107.2	110.7	114.5	117.5	119.9	123.0	127.3	131.6
92												
93	**R/$ exchange rate**		1	2	3	4	5	6	7	8	9	10
94	Initial R/$ exchange rate	6.00										
95	US Inflation index		102.70	104.75	107.22	110.72	114.52	117.52	119.93	123.02	127.28	131.63
96	RSA Inflation index		107.00	113.76	119.83	126.79	135.90	146.06	155.40	164.59	176.11	190.46
97	Exchange rate		6.00	6.25	6.44	6.59	6.83	7.16	7.46	7.70	7.97	8.33
98												



<u>Table 31:</u> Assumptions and calculations for the inflation rate projections.

4.4 Economic and risk analysis of the projects

Freesia Industries uses the net present value (NPV) as the criterion for the economic feasibility of a project. The minimum acceptable rate of return (MARR) of 13%, which consists of the risk-free rate (8%) plus a margin for profit (5%).

Project risk is defined as the probability that the project will be unable to generate the returns needed to cover the MARR, which is equivalent to the probability of a negative NPV. The MARR does not include a risk margin, as the project risk will be determined explicitly with Monte Carlo simulations (as explained in section 2.4.5). For this purpose the company has a project risk threshold of 20%, which means that an individual project will be considered too risky if its risk exceeds 20%.

Table 32 shows the project assumptions for one of the new projects being considered, namely project *Euroshaft*. Column B shows the most likely estimates for the assumptions. Columns C – E show how the uncertainty regarding these assumptions have been described. For this purpose the model allows the decision-maker to describe the uncertainties in terms of the three probability distributions as described in section 2.4.5, namely “U” for the uniform distribution, “N” for the normal distribution and “T” for the triangular distribution. For example, the equipment that must be acquired at a $-price at the start of the project has a normal distribution with an average of $23m and a standard deviation of $5m.

The estimate (column G) for each parameter is derived by extracting a value from the parameter’s cumulative probability distribution with the random numbers generated in column F.

	A	B	C	D	E	F	G
17							
18	**Project Assumptions (R000's)**						
19			**Distr.**	**P1**	**P2**	**Random**	**Estimate**
20	**Capital investment at start:**						
21	Land	10,000	T	9,000	12,000	0.2316	9,834
22	Building	30,000	U	25,000	35,000	0.965	34,651
23	Equipment	50,000	N	50,000	3,000	0.715	51,705
24	Equipment ($)	23,000	N	23,000	5,000	0.679	25,319
25	Construction	10,000	U	10,000	10,000	0.870	10,000
26	Installation	3,000	T	2,500	4,000	0.826	3,489
27	Opportunity cost	-	U	-	-	0.869	-
28	**Capital investment at time 1:**						
29	Land	-	U	-	-	0.7167	-
30	Building	-	U	-	-	0.785	-
31	Equipment	35,000	N	35,000	5,000	0.401	33,748
32	Equipment ($)	-	U	-	-	0.668	-
33	Construction	10,000	U	9,000	11,000	0.800	10,600
34	Installation	-	U	-	-	0.238	-
35	Opportunity cost	-	U	-	-	0.784	-
36	**Working capital:**						
37	Inventory	15,000	U	15,000	15,000	0.061	15,000
38	Accounts receivable	5,000	U	5,000	5,000	0.134	5,000
39	Other assets	-	U	-	-	0.396	-
40	Payables and accruals	-	U	-	-	0.067	-
41	Deferred tax	-	U	-	-	0.942	-
42							
43	**Sales Product A:**						
44	Initial sales volume	400	N	400	50	0.524	403
45	Annual increase margin	2%	U	1.0%	3.0%	0.506	2.0%
46	Initial price ($)	6.00	U	6.00	6.00	0.453	6.00
47							
48	**Sales Product B:**						
49	Initial sales volume	200	N	200	15	0.328	193
50	Annual increase margin	2%	N	2.0%	1.5%	0.693	2.8%
51	Initial price	21.00	U	21	21	0.634	21
52	**Expense reductions:**						
53	Initial expense reduction	20,000	N	20,000	3,000	0.478	19,834
54	**Labour:**						
55	Additional labour required	200	T	180	210	0.686	200
56	Labour cost	60	U	60	60	0.912	60
57							
58	Annual incremental costs	2,500	U	2,300	2,700	0.714	2,585

Table 32: Assumptions for the cash flow projections of project Euroshaft.

Table 33 shows the detailed cash flow calculations, based on the above assumptions.

	A	B	C	D	E	F	G	H	I	J	K	L
59												
60		0	1	2	3	4	5	6	7	8	9	10
61	Exchange rate	6.00	6.00	6.27	6.47	6.59	6.78	7.11	7.50	7.79	7.99	8.25
62												
63	Termination proceeds =	-										
64												
65	Capital investment:											
66	Land	-9,295	-	-	-	-	-	-	-	-	-	-
67	Buildings	-29,753	-	-	-	-	-	-	-	-	-	-
68	Equipment	-47,592	-31,618	-	-	-	-	-	-	-	-	-
69	Imported equipment ($)	-24,509	-	-	-	-	-	-	-	-	-	-
70	R-value	-147,054	-	-	-	-	-	-	-	-	-	-
71	Construction	-10,000	-9,010	-	-	-	-	-	-	-	-	-
72	Installation	-3,304	-	-	-	-	-	-	-	-	-	-
73	Opportunity Cost	-	-	-	-	-	-	-	-	-	-	-
74		-246,999	-40,628	-	-	-	-	-	-	-	-	-
75												
76	Working capital:											
77	Inventory	-15,000	-	-	-	-	-	-	-	-	-	-
78	Accounts receivable	-5,000	-	-	-	-	-	-	-	-	-	-
79	Other assets	-	-	-	-	-	-	-	-	-	-	-
80	Payables and accruals	-	-	-	-	-	-	-	-	-	-	-
81	Deferred tax	-	-	-	-	-	-	-	-	-	-	-
82		-20,000	-	-	-	-	-	-	-	-	-	20,000
83												
84	Positive cash flows											
85												
86	Product A:											
87	Sales forecast (calculated)		501	538	579	627	680	736	797	868	950	1,040
88	Sales growth			7.2%	7.7%	8.3%	8.4%	8.2%	8.3%	9.0%	9.5%	9.4%
89	$-price		6.00	6.16	6.28	6.44	6.66	6.88	7.04	7.19	7.40	7.67
90	Exchange rate		6.00	6.27	6.47	6.59	6.78	7.11	7.50	7.79	7.99	8.25
91	Revenue		18,051	20,777	23,521	26,603	30,669	35,960	42,049	48,610	56,180	65,756
92												
93	Product B:											
94	Sales forecast (calculated)		205	210	213	217	221	227	233	239	243	248
95	Sales growth			2.3%	1.8%	1.6%	2.0%	2.6%	2.8%	2.4%	1.9%	1.9%
96	$-price		21.00	21.57	21.99	22.54	23.30	24.06	24.63	25.15	25.91	26.84
97	Exchange rate		6.00	6.27	6.47	6.59	6.78	7.11	7.50	7.79	7.99	8.25
98	Revenue		25,805	28,335	30,324	32,179	34,903	38,812	43,066	46,767	50,299	54,830
99												
100	Expense reductions:											
101	Forecast reductions		18,401	19,689	20,983	22,168	23,363	24,816	26,645	28,697	30,706	32,606
102												
103	TOTAL	-	62,256	68,801	74,828	80,950	88,935	99,588	111,760	124,073	137,184	153,192
104												
105	Negative cash flows											
106	Incremental labourers		193	193	193	193	193	193	193	193	193	193
107	Labour cost		-60	-64	-68	-72	-76	-81	-87	-94	-99	-105
108	Incremental labour		-11,552	-12,361	-13,156	-13,872	-14,643	-15,640	-16,833	-18,024	-19,121	-20,312
109												
110	Other Incremental costs											
111	Annual		-2,389	-2,556	-2,724	-2,878	-3,033	-3,222	-3,459	-3,726	-3,986	-4,233
112	Specific		-1,300	-2,300	-5,000	-10,000	-	-	-	-	-	-
113												
114	TOTAL	-	-15,241	-17,217	-20,880	-26,750	-17,676	-18,862	-20,293	-21,749	-23,108	-24,546
115												
116	Depreciation:											
117	Depreciation rate											
118	Total depreciation		7,921	7,921	7,921	7,921	7,921	-	-	-	-	-
119	Outstanding term	5										
120	Tax	38%										
121												
122	Depreciation Tax Shield		3,010	3,010	3,010	3,010	3,010	-	-	-	-	-
123												
124	Salvage Value											
125	Land											9,295
126	Buildings											29,753
127	Equipment											15,842
128	TOTAL	-	-	-	-	-	-	-	-	-	-	54,891

Table 33: Detailed cash flow calculations for project Euroshaft.

From these detailed cash flow calculations, the projected cash flows for project Euroshaft can be summarized as shown in Table 34.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Project Input Sheet											
2												
3	Project:	EuroShaft										
4	Type:	New										
5												
6	EuroShaft	0	1	2	3	4	5	6	7	8	9	10
7	Capital Investment	-246,999	-40,628	-	-	-	-	-	-	-	-	-
8	Working capital	-20,000	-	-	-	-	-	-	-	-	-	20,000
9	Positive cash flows	-	62,256	68,801	74,828	80,950	88,935	99,588	111,760	124,073	137,184	-
10	Negative cash flows	-	-15,241	-17,217	-20,880	-26,750	-17,676	-18,862	-20,293	-21,749	-23,108	-24,546
11	Depreciation tax shield	-	3,010	3,010	3,010	3,010	3,010	-	-	-	-	-
12	Salvage value	-	-	-	-	-	-	-	-	-	-	54,891
13	Net cash flows	-266,999	9,397	54,594	56,958	57,211	74,269	80,726	91,467	102,324	114,077	50,345
14												
15	IRR =	17.8%										
16	NPV =	67,895										

<u>Table 34:</u> Summary of projected cash flows for project Euroshaft.

Table 34 also shows two decision criteria, namely the internal rate of return (IRR) of 17.8% and the NPV of about R68m.

The type of analysis described above is done for all the projects, both the new project candidates and the existing projects. For some of the existing projects, the company also has the option to terminate the project. It is important to estimate the net termination proceeds for those projects where termination is an option.

Since the assumptions were formulated in terms of probability distributions, the cash flows for project Euroshaft in Table 34 is but one feasible set of cash flows for one possible version of the future. In order to get an idea of what the expected cash flows could be, the above process can be repeated for say 1,000 times through the process of Monte Carlo simulation. The results of the Monte Carlo simulation will give a more accurate indication of the project's characteristics. Table 35 shows an extract of the Monte Carlo simulation, which was run 1,000 times.

	EuroShaft			
			Risk =	9%
			Stdev =	43,099
	CF0	CF1	CF2	NPV
Average =	-257,487	2,227	51,817	60,729
1	-240,803	12,869	58,602	130,502
2	-279,273	6,877	49,039	28,549
3	-247,678	389	49,931	57,193
4	-268,897	-4,417	50,340	29,668
5	-223,086	9,455	57,763	144,857
6	-266,694	13,257	58,752	104,205
7	-281,096	6,049	58,222	66,456
8	-219,095	1,070	53,828	116,825
9	-257,699	4,042	53,365	87,130
10	-214,189	2,146	61,788	158,672
11	-296,937	7,914	51,212	14,275
12	-262,656	-1,922	54,206	69,785
13	-250,023	1,094	42,420	5,854
14	-309,484	-5,159	50,441	7,597
15	-262,123	6,549	56,139	64,285
16	-257,758	3,633	56,034	65,929
17	-230,147	-3,943	54,731	103,669
18	-226,265	-3,250	49,900	77,590
19	-267,057	4,653	49,849	38,480
20	-200,688	2,221	50,782	108,045
21	-292,826	-2,609	48,698	22,521
22	-291,231	8,058	50,177	15,643
23	-246,810	2,884	48,472	46,427
24	-255,875	-7,862	44,910	22,068
25	-226,622	-3,563	52,851	105,520
26	-249,839	1,688	52,913	84,316
27	-269,289	-4,982	52,085	40,087
28	-292,139	-1,884	51,139	33,324
29	-234,859	7,270	64,095	164,619
30	-264,858	-2,412	53,783	69,073

Table 35: A sample of the Monte Carlo simulation results for project Euroshift.

The average NPV of nearly R61m is a much better estimate than the R68m in Table 34. Table 35 also shows the standard deviation in the NPV and also the % of the Monte Carlo runs which resulted in negative NPV's. For the Euroshaft project 9% of the 1,000 simulation runs resulted in negative NPV's. It is therefore reasonable to say that there is a 9% probability of a negative NPV or that the project risk is therefore 9%. Since the risk threshold on an individual project is 20%, the new Euroshaft project qualifies for further consideration.

Table 36 shows the following results of the Monte Carlo simulation runs done for all the projects: the average initial net capital flow, the average capital flows after the first and the second years, the average NPV and each project's risk in terms of probability of negative NPV's.

	Net cash flow					
	0	1	2	NPV	sdev	Risk
EuroShaft	-261,727	2,334	51,671	55,543	42,830	10%
Aston	-327,132	20,142	73,196	149,214	141,114	14%
Ultra	-274,320	5,302	54,709	70,781	72,899	17%
Sabie	-52,666	-29,060	16,259	9,790	10,964	17%
Hertz	-622,567	-13,088	136,632	398,157	181,281	1%
Bank	-58,171	1,402	10,652	38,848	16,353	1%
Discover	-260,474	-3,013	46,805	43,187	39,143	14%
Namaqua	-	38,310	42,223	198,010	30,360	0%
Landmax	-	26,920	29,506	120,550	4,986	0%
Brakflow	-	21,867	23,605	115,088	14,894	0%
Fourport	-	59,747	69,056	359,306	42,523	0%
Extrema	-	26,137	29,378	145,732	10,841	0%
LevelOne	-	40,036	45,200	219,929	14,121	0%
Hever	-	18,682	20,873	151,308	14,050	0%
Castle	-	41,148	46,070	133,428	20,513	0%
Kwasand	-	39,882	44,187	151,655	9,215	0%
Terminate Namaqua	103,224	-	-	103,224	6,159	0%
Terminate Landmax	83,500	-	-	83,500	6,013	0%
Terminate Brakflow	100,435	-	-	100,435	15,418	0%
Terminate Fourport	259,563	-	-	259,563	21,505	0%
Terminate Extrema	129,797	-	-	129,797	19,907	0%
Terminate LevelOne	149,865	-	-	149,865	40,167	0%
Terminate Hever	138,596	-	-	138,596	28,655	0%
Terminate Castle	111,284	-	-	111,284	20,044	0%
Terminate Kwasand	137,011	-	-	137,011	13,081	0%

Table 36: **Averages for all the projects after the Monte Carlo simulation runs (R000's)**

4.5 Project analysis in terms of the multiple objectives

In section 4.1 it was stated that the objective for the company is to find the optimal portfolio of projects that does not only take economics into account, but that also considers the other important company objectives and constraints. The aim of this section is therefore to analyze and score the projects in terms of the company's multiple objectives.

The first steps have already been completed in section 4.2 where the company's multiple objectives and their relative weights have been determined as economic feasibility (60%), health and safety (20%), customer satisfaction (10%), reputation in the market (6%) and social responsibility (4%).

Since the economic feasibility of each project has already been determined, one can use the NPV's to score each project in terms of this objective, as shown in Table 37. The economic feasibility score for a project is simply the ratio of its NPV to the sum of the NPV's of all the projects. Table 37 also shows the ranking of the projects in terms of economic feasibility.

	NPV	Economic feasibility	Ranking
EuroShaft	55,543	1.55%	22
Aston	149,214	4.18%	9
Ultra	70,781	1.98%	21
Sabie	9,790	0.27%	25
Hertz	398,157	11.14%	1
Bank	38,848	1.09%	24
Discover	43,187	1.21%	23
Namaqua	198,010	5.54%	5
Landmax	120,550	3.37%	15
Brakflow	115,088	3.22%	16
Fourport	359,306	10.05%	2
Extrema	145,732	4.08%	10
LevelOne	219,929	6.15%	4
Hever	151,308	4.23%	7
Castle	133,428	3.73%	13
Kwasand	151,655	4.24%	6
Terminate Namaqua	103,224	2.89%	18
Terminate Landmax	83,500	2.34%	20
Terminate Brakflow	100,435	2.81%	19
Terminate Fourport	259,563	7.26%	3
Terminate Extrema	129,797	3.63%	14
Terminate LevelOne	149,865	4.19%	8
Terminate Hever	138,596	3.88%	11
Terminate Castle	111,284	3.11%	17
Terminate Kwasand	137,011	3.83%	12
	3,573,800	100%	

Table 37: Project scores in terms of economic feasibility

The other four objectives are more difficult to score, as there are no tangible measures that can indicate to what extent a project contribute to them. Step 3 under section 3.5 describes two ways of dealing with this problem. The first one was to do pairwise comparisons between the projects for each of the objectives (see Table 26) and the second one was to do a comparative rating of the projects in respect of the objectives (see Table 27). Table 38 shows the comparative ratings for all the projects in respect of these four objectives.

	COMPARATIVE RATING				WEIGHTS			
PROJECTS	Health and safety	Customer satisfaction	Reputation in the market	Social responsibility	Health and safety	Customer satisfaction	Reputation in the market	Social responsibility
EuroShaft	-	2	4	3	0.00%	3.92%	6.78%	5.36%
Aston	5	1	4	5	10.64%	1.96%	6.78%	8.93%
Ultra	1	1	2	2	2.13%	1.96%	3.39%	3.57%
Sabie	2	5	-	2	4.26%	9.80%	0.00%	3.57%
Hertz	-	1	3	4	0.00%	1.96%	5.08%	7.14%
Bank	-	5	3	3	0.00%	9.80%	5.08%	5.36%
Discover	3	4	1	-	6.38%	7.84%	1.69%	0.00%
Namaqua	2	1	2	-	4.26%	1.96%	3.39%	0.00%
Landmax	5	1	5	4	10.64%	1.96%	8.47%	7.14%
Brakflow	1	2	3	3	2.13%	3.92%	5.08%	5.36%
Fourport	5	2	2	1	10.64%	3.92%	3.39%	1.79%
Extrema	2	2	5	1	4.26%	3.92%	8.47%	1.79%
LevelOne	2	5	4	4	4.26%	9.80%	6.78%	7.14%
Hever	5	2	3	4	10.64%	3.92%	5.08%	7.14%
Castle	4	4	4	4	8.51%	7.84%	6.78%	7.14%
Kwasand	4	3	3	3	8.51%	5.88%	5.08%	5.36%
Terminate Namaqua	-	2	-	1	0.00%	3.92%	0.00%	1.79%
Terminate Landmax	1	2	1	2	2.13%	3.92%	1.69%	3.57%
Terminate Brakflow	-	1	2	1	0.00%	1.96%	3.39%	1.79%
Terminate Fourport	2	1	1	5	4.26%	1.96%	1.69%	8.93%
Terminate Extrema	1	1	1	1	2.13%	1.96%	1.69%	1.79%
Terminate LevelOne	-	1	2	2	0.00%	1.96%	3.39%	3.57%
Terminate Hever	1	-	1	-	2.13%	0.00%	1.69%	0.00%
Terminate Castle	-	1	2	-	0.00%	1.96%	3.39%	0.00%
Terminate Kwasand	1	1	1	1	2.13%	1.96%	1.69%	1.79%
	47	51	59	56	100%	100%	100%	100%

<u>Table 38:</u> Comparative rating and weighing of projects in respect of the objectives other than economic feasibility.

By multiplying the weights in Tables 35 and 36 with the weights of the multiple objectives, one can derive each project's multiple objective score. These are shown in Table 39.

	A	B	C	D	E	F	G
1		Economic feasibility	Health and safety	Customer satisfaction	Reputation in the market	Social responsibility	Multiple objective score
2	PROJECTS	60%	20%	10%	6%	4%	
3	EuroShaft	1.55%	0.00%	3.92%	6.78%	5.36%	1.95
4	Aston	4.18%	10.64%	1.96%	6.78%	8.93%	5.59
5	Ultra	1.98%	2.13%	1.96%	3.39%	3.57%	2.16
6	Sabie	0.27%	4.26%	9.80%	0.00%	3.57%	2.14
7	Hertz	11.14%	0.00%	1.96%	5.08%	7.14%	7.47
8	Bank	1.09%	0.00%	9.80%	5.08%	5.36%	2.15
9	Discover	1.21%	6.38%	7.84%	1.69%	0.00%	2.89
10	Namaqua	5.54%	4.26%	1.96%	3.39%	0.00%	4.57
11	Landmax	3.37%	10.64%	1.96%	8.47%	7.14%	5.14
12	Brakflow	3.22%	2.13%	3.92%	5.08%	5.36%	3.27
13	Fourport	10.05%	10.64%	3.92%	3.39%	1.79%	8.83
14	Extrema	4.08%	4.26%	3.92%	8.47%	1.79%	4.27
15	LevelOne	6.15%	4.26%	9.80%	6.78%	7.14%	6.22
16	Hever	4.23%	10.64%	3.92%	5.08%	7.14%	5.65
17	Castle	3.73%	8.51%	7.84%	6.78%	7.14%	5.42
18	Kwasand	4.24%	8.51%	5.88%	5.08%	5.36%	5.36
19	Terminate Namaqua	2.89%	0.00%	3.92%	0.00%	1.79%	2.20
20	Terminate Landmax	2.34%	2.13%	3.92%	1.69%	3.57%	2.46
21	Terminate Brakflow	2.81%	0.00%	1.96%	3.39%	1.79%	2.16
22	Terminate Fourport	7.26%	4.26%	1.96%	1.69%	8.93%	5.86
23	Terminate Extrema	3.63%	2.13%	1.96%	1.69%	1.79%	2.97
24	Terminate LevelOne	4.19%	0.00%	1.96%	3.39%	3.57%	3.06
25	Terminate Hever	3.88%	2.13%	0.00%	1.69%	0.00%	2.85
26	Terminate Castle	3.11%	0.00%	1.96%	3.39%	0.00%	2.27
27	Terminate Kwasand	3.83%	2.13%	1.96%	1.69%	1.79%	3.09
28		100%	100%	100%	100%	100%	100.00

Table 39: Calculation of each project's multiple objective score.

Column G in Table 39 indicates each project's multiple objective score. These scores are calculated according to the formula given in step 4 of section 3.5. As an example, the score for the third project, Ultra, is calculated as follows:

Score = (0.6 x 1.98) + (0.2 x 2.13) + (0.1 x 1.96) + (0.06 x 3.39) + (0.04 x 3.57)
= 2.16.

It is interesting to note how the ranking of the projects according to the multiple objective scoring changed when compared to the ranking according to the NPV's (see Table 40). A good example is project Namaqua that is ranked 5th on the NPV-ranking, but that dropped to 10th place on the multiple objective ranking, as a result of low rating on the intangible objectives.

	A	B	C
1, 2	PROJECTS	NPV Ranking	MO ranking
3	Hertz	1	2
4	Fourport	2	1
5	Terminate Fourport	3	4
6	LevelOne	4	3
7	Namaqua	5	10
8	Kwasand	6	8
9	Hever	7	5
10	Terminate LevelOne	8	14
11	Aston	9	6
12	Extrema	10	11
13	Terminate Hever	11	17
14	Terminate Kwasand	12	13
15	Castle	13	7
16	Terminate Extrema	14	15
17	Landmax	15	9
18	Brakflow	16	12
19	Terminate Castle	17	19
20	Terminate Namaqua	18	20
21	Terminate Brakflow	19	21
22	Terminate Landmax	20	18
23	Ultra	21	22
24	EuroShaft	22	25
25	Discover	23	16
26	Bank	24	23
27	Sabie	25	24

Table 40: Changes to the project rankings as a result of introducing multiple objective scoring.

Whereas the multiple objective scores cannot be expressed in terms of known units, it must be interpreted as a relative measure of support for the company's multiple objectives.

In order to formulate the multiple objective function (MOF) for Freesia Industries, it is necessary to first define the decision variable x_i, where $i = 1, 2, ..., 25$, as the variable that can either be equal to 0 or 1 and which will be determined by the optimization program. When $x_i = 1$, it means that project i has been selected to be part of the company's optimal portfolio of projects. Conversely, if $x_i = 0$, it means that the optimization program has excluded project i from the company's optimal portfolio of projects.

Table 41 shows each project's multiple objective score and its corresponding decision variable.

	PROJECT	MULTIPLE OBJECTIVE SCORE	DECISION VARIABLE
NEW PROJECTS	Euroshaft	1.95	x_1
	Aston	5.59	x_2
	Ultra	2.16	x_3
	Sabie	2.14	x_4
	Hertz	7.47	x_5
	Bank	2.15	x_6
	Discover	2.89	x_7
EXISTING PROJECTS	Namaqua	4.57	x_8
	Landmax	5.14	x_9
	Brakflow	3.27	x_{10}
	Fourport	8.83	x_{11}
	Extrema	4.27	x_{12}
	LevelOne	6.22	x_{13}
	Hever	5.65	x_{14}
	Castle	5.42	x_{15}
	Kwasand	5.36	x_{16}
	Terminate Namaqua	2.20	x_{17}
	Terminate Landmax	2.46	x_{18}
	Terminate Brakflow	2.16	x_{19}
	Terminate Fourport	5.86	x_{20}
	Terminate Extrema	2.97	x_{21}
	Terminate LevelOne	3.06	x_{22}
	Terminate Hever	2.85	x_{23}
	Terminate Castle	2.27	x_{24}
	Terminate Kwasand	3.09	x_{25}

Table 41: Project multiple objective scores and decision variables

The multiple objective function (MOF) can therefore be formulated as follows:

$$\begin{aligned} MOF = \; & 1.95\, x_1 + 5.59\, x_2 + 2.16\, x_3 + 2.14\, x_4 + 7.47\, x_5 + \\ & 2.15\, x_6 + 2.89\, x_7 + 4.57\, x_8 + 5.14\, x_9 + 3.27\, x_{10} + \\ & 8.83\, x_{11} + 4.27\, x_{12} + 6.22\, x_{13} + 5.65\, x_{14} + 5.42\, x_{15} + \\ & 5.36\, x_{16} + 2.20\, x_{17} + 2.46\, x_{18} + 2.16\, x_{19} + 5.86\, x_{20} + \\ & 2.97\, x_{21} + 3.06\, x_{22} + 2.85\, x_{23} + 2.27\, x_{24} + 3.09\, x_{25} \end{aligned}$$

4.6 The constraints and the logical project interrelationships

As explained in section 3.8 the company may not be able to implement all the projects that might have passed its selection criteria, due to certain constraints that cannot be removed. There might also be certain relationships between some of the projects that will dictate the selection process.

The objective of this section is to illustrate how to accommodate such constraints and also how to specify special project interrelationships.

Constraints

In the case of Freesia Industries, two constraints will be included, namely the constraints on the availability of capital and labour for the selected portfolio, as specified in Table 42.

	CONSTRAINT	LIMIT
1.	Net capital outflow at start	R750m
2.	Net capital outflow during the 1st year	R200m
3.	Net capital outflow during the 2nd year	R100m
4.	Total initial labour force on capital projects	1,750

Table 42: Capital and labour constraints for Freesia Industries

In order for the optimization program to take these constraints into account, it will be necessary to extract these variables for each of the projects into the optimization program. The optimization program will ensure that the capital and labour requirements of the selected portfolio of projects do not exceed these constraints.

Project Interrelationships

It is important to identify any special project relationships that might exist and to ensure that the model incorporates them so that the final portfolio does not produce answers that cannot be allowed in practice.

Freesia Industries identified five such relationships, as described in Table 43.

	RELATIONSHIP	MODEL CONSTRAINT
1.	One of the new project *Euroshaft* (x_1) or the existing project *Namaqua* (x_8), or neither, but not both.	$x_1 + x_8 \leq 1$
2.	New project *Ultra* (x_3) only if existing project *Landmax is terminated* (x_{18}).	$x_3 - x_{18} \leq 0$
3.	One of the new project *Sabie* (x_4) or the existing project *Brakflow* (x_{10}), or both.	$x_4 + x_{10} \geq 1$
4.	Both the new projects *Hertz* (x_5) or *Bank* (x_6), or neither.	$x_5 - x_6 = 0$
5.	One of the new project *Discover* (x_7) or the existing project *Fourport* (x_{11}), but not both.	$x_7 + x_{11} = 1$

<u>Table 43:</u> Special project relationships

Existing projects

It will be noted from Table 41 that the "continue" and "terminate" decisions regarding existing projects have been incorporated as separate decision variables. For example, in the decision variables, there is a variable x_8 for existing project *Namaqua* and it has a multiple objective score of 4.57. If $x_8 = 1$, it means that the company must continue with the existing project *Namaqua* and that this decision will contribute 4.57 to the value of the multiple objective function (MOF). However if $x_8 = 0$, it means that the company must terminate the existing project *Namaqua*. The termination decision means that the project cannot contribute its score of 4.57 to the value of the MOF. Capital projects however have termination values which normally exceed zero and which differ from their continuation values. Hence the need to introduce the decision variable x_{17}, which if equal to 1 will indicate the *termination of project Namaqua* and the contribution of 2.20 to the value of the MOF. It should be clear that since a project cannot be both continued and terminated that one cannot have a situation where both $x_8 = 1$ and $x_{17} = 1$ or where both $x_8 = 0$ and $x_{17} = 0$. If $x_8 = 1$ then the model must set $x_{17} = 0$, or if $x_8 = 0$ then the model must set $x_{17} = 1$. This can be achieved by introducing the following constraint into the model:

$$x_8 + x_{17} = 1$$

Table 44 lists these constraints for all the existing projects.

PROJECT	EXISTING PROJECT CONSTRAINT
Namaqua	$x_8 + x_{17} = 1$
Landmax	$x_9 + x_{18} = 1$
Brakflow	$x_{10} + x_{19} = 1$
Fourport	$x_{11} + x_{20} = 1$
Extrema	$x_{12} + x_{21} = 1$
LevelOne	$x_{13} + x_{22} = 1$
Hever	$x_{14} + x_{23} = 1$
Castle	$x_{15} + x_{24} = 1$
Kwasand	$x_{16} + x_{25} = 1$

Table 44: Existing project constraints

4.7 The optimal portfolio

The objective of this section is to demonstrate how the What'sBest solver program can be used to find the optimal portfolio of capital projects for Freesia Industries.

Project analysis input

Table 45 shows the results of the project analyses that form the input to the optimization program.

	A	D	E	F	G	H		I
1		PROJECT ANALYSIS INPUT						
2	Project	Cash flow 0	Cash flow 1	Cash flow 2	Labour	NPV	sdev	MO-Score
3	EuroShaft	-261,727	2,334	51,671	200	55,543	42,830	1.95
4	Aston	-327,132	20,142	73,196	300	149,214	141,114	5.59
5	Ultra	-274,320	5,302	54,709	100	70,781	72,899	2.16
6	Sabie	-52,666	-29,060	16,259	50	9,790	10,964	2.14
7	Hertz	-622,567	-13,088	136,632	10	398,157	181,281	7.47
8	Bank	-58,171	1,402	10,652	35	38,848	16,353	2.15
9	Discover	-260,474	-3,013	46,805	200	43,187	39,143	2.89
10	Namaqua	-	38,310	42,223	200	198,010	30,360	4.57
11	Landmax	-	26,920	29,506	100	120,550	4,986	5.14
12	Brakflow	-	21,867	23,605	200	115,088	14,894	3.27
13	Fourport	-	59,747	69,056	200	359,306	42,523	8.83
14	Extrema	-	26,137	29,378	200	145,732	10,841	4.27
15	LevelOne	-	40,036	45,200	200	219,929	14,121	6.22
16	Hever	-	18,682	20,873	200	151,308	14,050	5.65
17	Castle	-	41,148	46,070	150	133,428	20,513	5.42
18	Kwasand	-	39,882	44,187	200	151,655	9,215	5.36
19	Terminate Namaqua	103,224	-	-	-	103,224	6,159	2.20
20	Terminate Landmax	83,500	-	-	-	83,500	6,013	2.46
21	Terminate Brakflow	100,435	-	-	-	100,435	15,418	2.16
22	Terminate Fourport	259,563	-	-	-	259,563	21,505	5.86
23	Terminate Extrema	129,797	-	-	-	129,797	19,907	2.97
24	Terminate LevelOne	149,865	-	-	-	149,865	40,167	3.06
25	Terminate Hever	138,596	-	-	-	138,596	28,655	2.85
26	Terminate Castle	111,284	-	-	-	111,284	20,044	2.27
27	Terminate Kwasand	137,011	-	-	-	137,011	13,081	3.09
28					2,545			100.00

<u>Table 45:</u> Project analysis input to optimization program (all R-amounts in R000's).

Since the company has put constraints (see Table 42) on the net capital investment amounts for the first three periods and on the total initial labour force, it was necessary to extract this information for each project (see columns D, E, F and G in Table 45). Each project's net present value (NPV) was also extracted (see column H in Table 45), as management will be want to know what the NPV of the eventual portfolio will be. Lastly, each project's multiple objective score (MO-score in column I of Table 45) was extracted to enable the program to calculate the multiple objective function (MOF).

Decision variables

In the model each project is linked to its own decision variable, which will indicate the choices made by the optimization program for each project. In the case of Freesia Industries it will only be necessary to incorporate integer 0/1-variables where "1" will indicate the selection of a project and "0" the exclusion of a project. Table 46 shows all the projects with their corresponding decision variables and illustrative values in column C.

	A	B	C
1			
2	Project	Selection	
3	EuroShaft	$x1$	0
4	Aston	$x2$	1
5	Ultra	$x3$	1
6	Sabie	$x4$	1
7	Hertz	$x5$	1
8	Bank	$x6$	1
9	Discover	$x7$	0
10	Namaqua	$x8$	1
11	Landmax	$x9$	1
12	Brakflow	$x10$	1
13	Fourport	$x11$	1
14	Extrema	$x12$	1
15	LevelOne	$x13$	1
16	Hever	$x14$	1
17	Castle	$x15$	1
18	Kwasand	$x16$	1
19	Terminate Namaqua	$x17$	0
20	Terminate Landmax	$x18$	0
21	Terminate Brakflow	$x19$	0
22	Terminate Fourport	$x20$	0
23	Terminate Extrema	$x21$	0
24	Terminate LevelOne	$x22$	0
25	Terminate Hever	$x23$	0
26	Terminate Castle	$x24$	0
27	Terminate Kwasand	$x25$	0

Table 46: Decision variables in the model.

Existing project constraints

The existing project constraints as explained in section 4.6, are included in the model, as shown in Table 47.

	J	K	L	M	N	O
32	Existing projects:					
33		Namaqua	1	=	1	
34		Landmax	1	=	1	
35		Brakflow	1	=	1	
36		Fourport	1	=	1	
37		Extrema	1	=	1	
38		LevelOne	1	=	1	
39		Hever	1	=	1	
40		Castle	1	=	1	
41		Kwasand	1	=	1	

Table 47: Existing project constraints in the model.

Columns L, M and N in Table 47 contain the formulae of Table 44 that will ensure that the model either select or decline each of the existing projects.

Project interrelationships

The project interrelationships described in section 4.6, are included in the model, as shown in Table 48.

	J	K	L	M	N	O
42						
43		Either Euroshaft or Namaqua, or neither, but not both:		1	=<=	1
44			Ultra only if Landmax is continued:	0	=<=	0
45			One of Sabie or Brakflow, or both:	2	>=	1
46			Both Hertz and Bank, or neither:	0	=	0
47			One of Discover or Fourport, but not both:	1	=	1

Table 48: Project interrelationships in the model.

Columns M, N and O in Table 48 contain the formulae of Table 43 that will ensure that the model's choices adhere to the logical relationships between these projects.

Portfolio characteristics

Once the optimization program has selected a set of decision variables, these variables can be multiplied with the project analysis input in order to produce a portfolio of projects.

	A	B	C	J	K	L	M	N	O
1				PORTFOLIO RESULTS					
2	Project	Selection		Cash flow 0	Cash flow 1	Cash flow 2	Labour	NPV	MO-Score
3	EuroShaft	x1	0	-	-	-	-	-	-
4	Aston	x2	1	-327,132	20,142	73,196	300	149,214	5.59
5	Ultra	x3	1	-274,320	5,302	54,709	100	70,781	2.16
6	Sabie	x4	1	-52,666	-29,060	16,259	50	9,790	2.14
7	Hertz	x5	1	-622,567	-13,088	136,632	10	398,157	7.47
8	Bank	x6	1	-58,171	1,402	10,652	35	38,848	2.15
9	Discover	x7	0	-	-	-	-	-	-
10	Namaqua	x8	1	-	38,310	42,223	200	198,010	4.57
11	Landmax	x9	1	-	26,920	29,506	100	120,550	5.14
12	Brakflow	x10	1	-	21,867	23,605	200	115,088	3.27
13	Fourport	x11	1	-	59,747	69,056	200	359,306	8.83
14	Extrema	x12	1	-	26,137	29,378	200	145,732	4.27
15	LevelOne	x13	1	-	40,036	45,200	200	219,929	6.22
16	Hever	x14	1	-	18,682	20,873	200	151,308	5.65
17	Castle	x15	1	-	41,148	46,070	150	133,428	5.42
18	Kwasand	x16	1	-	39,882	44,187	200	151,655	5.36
19	Terminate Namaqua	x17	0	-	-	-	-	-	-
20	Terminate Landmax	x18	0	-	-	-	-	-	-
21	Terminate Brakflow	x19	0	-	-	-	-	-	-
22	Terminate Fourport	x20	0	-	-	-	-	-	-
23	Terminate Extrema	x21	0	-	-	-	-	-	-
24	Terminate LevelOne	x22	0	-	-	-	-	-	-
25	Terminate Hever	x23	0	-	-	-	-	-	-
26	Terminate Castle	x24	0	-	-	-	-	-	-
27	Terminate Kwasand	x25	0	-	-	-	-	-	-
28	Portfolio Total =			-1,334,856	297,427	641,547	2,145	2,261,796	68.24

<u>Table 49:</u> Portfolio results in the model.

The portfolio therefore only consists of those projects whose decision variables (column C in Table 49) are equal to 1 and it is therefore only the results of those projects that form part of the selected portfolio. The portfolio in Table 49 suggests the continuation of all the existing projects and the commencement of five of the seven new projects. Table 49 shows that this portfolio requires capital of about R1.34bn (see cell J28) at the outset and that the portfolio produces a total NPV of R2.26bn (N28) and a total value of the multiple objective function (MOF) of 68.17 (O28).

Constraints

The portfolio in Table 49 however does not adhere to the constraints as formulated in Table 42, especially the limit on the net capital outflow at the start of R750m and the initial labour force of 1,750. Table 50 shows how these constraints can be included in the model.

	A	B	C	J	K	L	M	N	O
1				PORTFOLIO RESULTS					
2	Project	Selection		Cash flow 0	Cash flow 1	Cash flow 2	Labour	NPV	MO-Score
28			Portfolio Total =	-1,334,856	297,427	641,547	2,145	2,261,796	68.24
29				>=	>=	>=	<=		
30				-750,000	-200,000	-100,000	1,750		

<u>Table 50:</u> Specifying the constraints in the model. (R000's)

In Table 50,the values in row 28 indicate the values for the total portfolio. The values in row 30 represents the limitations that the company wants to place on certain parameters and the symbols in row 29 indicate the required relationships. For example the company does not want the net cash outflow at the start to exceed R750m, hence the constraint that the portfolio’s total net cash flow at the start (J28) must be equal to or greater than (>= in J29) than the limit of R750m (J30). Also one can see the constraint on the initial labour in column M, where it is required that the initial labour force should not exceed 1,750.

The optimal portfolio

It is clear from Table 50 that the portfolio shown in Table 49 does not adhere to the constraints above. Having set up the optimization problem as described in this section, one can now instruct the What’sBest program to solve and to find the optimal portfolio of projects. The result of this optimization is shown in Table 51.

	A	B	C	J	K	L	M	N	O
1				PORTFOLIO RESULTS					
2	Project	Selection		Cash flow 0	Cash flow 1	Cash flow 2	Labour	NPV	MO-Score
3	EuroShaft	$x1$	0	-	-	-	-	-	-
4	Aston	$x2$	1	-327,132	20,142	73,196	300	149,214	5.59
5	Ultra	$x3$	0	-	-	-	-	-	-
6	Sabie	$x4$	1	-52,666	-29,060	16,259	50	9,790	2.14
7	Hertz	$x5$	1	-622,567	-13,088	136,632	10	398,157	7.47
8	Bank	$x6$	1	-58,171	1,402	10,652	35	38,848	2.15
9	Discover	$x7$	0	-	-	-	-	-	-
10	Namaqua	$x8$	1	-	38,310	42,223	200	198,010	4.57
11	Landmax	$x9$	1	-	26,920	29,506	100	120,550	5.14
12	Brakflow	$x10$	0	-	-	-	-	-	-
13	Fourport	$x11$	1	-	59,747	69,056	200	359,306	8.83
14	Extrema	$x12$	0	-	-	-	-	-	-
15	LevelOne	$x13$	1	-	40,036	45,200	200	219,929	6.22
16	Hever	$x14$	1	-	18,682	20,873	200	151,308	5.65
17	Castle	$x15$	1	-	41,148	46,070	150	133,428	5.42
18	Kwasand	$x16$	0	-	-	-	-	-	-
19	Terminate Namaqua	$x17$	0	-	-	-	-	-	-
20	Terminate Landmax	$x18$	0	-	-	-	-	-	-
21	Terminate Brakflow	$x19$	1	100,435	-	-	-	100,435	2.16
22	Terminate Fourport	$x20$	0	-	-	-	-	-	-
23	Terminate Extrema	$x21$	1	129,797	-	-	-	129,797	2.97
24	Terminate LevelOne	$x22$	0	-	-	-	-	-	-
25	Terminate Hever	$x23$	0	-	-	-	-	-	-
26	Terminate Castle	$x24$	0	-	-	-	-	-	-
27	Terminate Kwasand	$x25$	1	137,011	-	-	-	137,011	3.09
28	Portfolio Total =			-693,293	204,239	489,668	1,445	2,145,783	61.41
29				>=	>=	>=	<=		
30				-750,000	-200,000	-100,000	1,750		

Table 51: The optimal portfolio.
(R000's)

The optimal portfolio in Table 51 shows a total portfolio NPV of R2.14bn, which is 5% lower than the NPV on the portfolio in Table 49. The value of the MOF of the optimal portfolio is 61.41. The model therefore recommends the decisions as described in Table 52.

	RECOMMENDATION	COMMENTS
1	Do not commence project *Euroshaft*.	Euroshaft has lowest MO-score. Also, the 1st project relationship in Table 43 was between projects *Euroshaft* and *Namaqua*: "either, or neither, but not both".
2	Commence project *Aston*.	With a high MO-score, the model included project *Aston* in the optimal portfolio.
3	Do not commence project *Ultra*.	With one of the lowest MO-scores, the model excluded project *Ultra* from the optimal portfolio.
4	Commence project *Sabie*.	Even though project *Sabie* has one of the lowest MO-scores, it was selected since the model opted for the termination of project *Brakflow* and because of the 3rd project relationship of "one of, or both" between project *Sabie* and project *Brakflow*.
5	Commence project *Hertz*.	With the highest NPV and the 2nd highest MO-score, project *Hertz* was included in the optimal portfolio.
6	Commence project *Bank*.	Even though project *Bank* has a very low MO-score, it was included because of its "both or neither" relationship with project *Hertz*.
7	Do not commence project *Discover*.	The project relationship between project *Discover* and project *Fourport* requires one of the two, but not both. Project *Fourport* (the project with the highest MO-score) was selected, hence the decision not to start project *Discover*.
8	Continue with project *Namaqua*.	The continuation option had a much higher MO-score.
9	Continue with project *Landmax*.	The continuation option had a much higher MO-score.
10	Terminate project *Brakflow*.	Terminated due to overall constraints and in order to optimize the portfolio.
11	Continue with project *Fourport*.	The continuation with project *Fourport* offered the highest MO-score.
12	Terminate project *Extrema*.	Terminated due to overall constraints and in order to optimize the portfolio.
13	Continue with project *LevelOne*.	The continuation with project *LevelOne* offered the 3rd highest MO-score.
14	Continue with project *Hever*.	Continuation preferred to termination.
15	Continue with project *Castle*.	Continuation preferred to termination.
16	Terminate project *Kwasand*.	Terminated due to overall constraints and in order to optimize the portfolio.

<u>Table 52:</u> The recommendations arising from the optimization program.

4.8 Objective function: multiple objective function (MOF) or net present value (NPV)

One of the key aspects of the approach proposed in this thesis is the use of the multiple objective function (MOF) as the objective function in the optimization program, as supposed to the portfolio's net present value (NPV). It would therefore be of interest to compare the answers given by these two objective functions.

By substituting each project's multiple objective score with its NPV in the optimization program, one can generate the optimal solution with NPV as the objective function as shown in Table 53.

	A	B	C	J	K	L	M	O
1				PORTFOLIO RESULTS				
2	Project	Selection		Cash flow 0	Cash flow 1	Cash flow 2	Labour	NPV
3	EuroShaft	$x1$	0	-	-	-	-	-
4	Aston	$x2$	1	-327,132	20,142	73,196	300	149,214.22
5	Ultra	$x3$	1	-274,320	5,302	54,709	100	70,780.88
6	Sabie	$x4$	1	-52,666	-29,060	16,259	50	9,789.94
7	Hertz	$x5$	1	-622,567	-13,088	136,632	10	398,157.12
8	Bank	$x6$	1	-58,171	1,402	10,652	35	38,847.78
9	Discover	$x7$	0	-	-	-	-	-
10	Namaqua	$x8$	1	-	38,310	42,223	200	198,010.47
11	Landmax	$x9$	1	-	26,920	29,506	100	120,549.95
12	Brakflow	$x10$	0	-	-	-	-	-
13	Fourport	$x11$	1	-	59,747	69,056	200	359,305.60
14	Extrema	$x12$	0	-	-	-	-	-
15	LevelOne	$x13$	1	-	40,036	45,200	200	219,928.99
16	Hever	$x14$	0	-	-	-	-	-
17	Castle	$x15$	0	-	-	-	-	-
18	Kwasand	$x16$	0	-	-	-	-	-
19	Terminate Namaqua	$x17$	0	-	-	-	-	-
20	Terminate Landmax	$x18$	0	-	-	-	-	-
21	Terminate Brakflow	$x19$	1	100,435	-	-	-	100,434.78
22	Terminate Fourport	$x20$	0	-	-	-	-	-
23	Terminate Extrema	$x21$	1	129,797	-	-	-	129,796.89
24	Terminate LevelOne	$x22$	0	-	-	-	-	-
25	Terminate Hever	$x23$	1	138,596	-	-	-	138,596.49
26	Terminate Castle	$x24$	1	111,284	-	-	-	111,283.85
27	Terminate Kwasand	$x25$	1	137,011	-	-	-	137,010.86
28	Portfolio Total =			-717,733	149,711	477,434	1,195	2,181,707.84
29				>=	>=	>=	<=	
30				-750,000	-200,000	-100,000	1,750	

<u>Table 53:</u> The optimal portfolio with NPV as the objective function

By comparing the "MOF-portfolio" in Table 51 with the "NPV-portfolio" in Table 53, one can see significant differences. The MOF-portfolio recommends the termination of 3 of the existing projects, whereas the NPV-portfolio recommends the termination of 5 of the existing projects. Another important difference is that the NPV of the NPV-portfolio is R36m higher than the NPV of the MOF-portfolio, which suggests that the NPV-portfolio will add more economic value to the company.

However to do a complete comparison, one should also compare both portfolios in terms of the company's other objectives. Table 54 presents an analysis of the NPV-portfolio in terms of the company's multiple objectives.

	A	B	C	X	Y	Z	AA	AB
1				Economic feasibility	Health and safety	Customer satisfaction	Reputation in the market	Social responsibility
2	Project	Selection		60%	20%	10%	6%	4%
3	EuroShaft	x_1	0	-	-	-	-	-
4	Aston	x_2	1	4.18	10.64	1.96	6.78	8.93
5	Ultra	x_3	1	1.98	2.13	1.96	3.39	3.57
6	Sabie	x_4	1	0.27	4.26	9.80	-	3.57
7	Hertz	x_5	1	11.14	-	1.96	5.08	7.14
8	Bank	x_6	1	1.09	-	9.80	5.08	5.36
9	Discover	x_7	0	-	-	-	-	-
10	Namaqua	x_8	1	5.54	4.26	1.96	3.39	-
11	Landmax	x_9	1	3.37	10.64	1.96	8.47	7.14
12	Brakflow	x_{10}	0	-	-	-	-	-
13	Fourport	x_{11}	1	10.05	10.64	3.92	3.39	1.79
14	Extrema	x_{12}	0	-	-	-	-	-
15	LevelOne	x_{13}	1	6.15	4.26	9.80	6.78	7.14
16	Hever	x_{14}	0	-	-	-	-	-
17	Castle	x_{15}	0	-	-	-	-	-
18	Kwasand	x_{16}	0	-	-	-	-	-
19	Terminate Namaqua	x_{17}	0	-	-	-	-	-
20	Terminate Landmax	x_{18}	0	-	-	-	-	-
21	Terminate Brakflow	x_{19}	1	2.81	-	1.96	3.39	1.79
22	Terminate Fourport	x_{20}	0	-	-	-	-	-
23	Terminate Extrema	x_{21}	1	3.63	2.13	1.96	1.69	1.79
24	Terminate LevelOne	x_{22}	0	-	-	-	-	-
25	Terminate Hever	x_{23}	1	3.88	2.13	-	1.69	-
26	Terminate Castle	x_{24}	1	3.11	-	1.96	3.39	-
27	Terminate Kwasand	x_{25}	1	3.83	2.13	1.96	1.69	1.79
28	Portfolio Total =			61.05	53.19	50.98	54.24	50.00
29								
30				Value ot the portfolio's Multiple objective function =				57.62

<u>Table 54:</u> Analysis of the NPV-portfolio in terms of the company's multiple objectives.

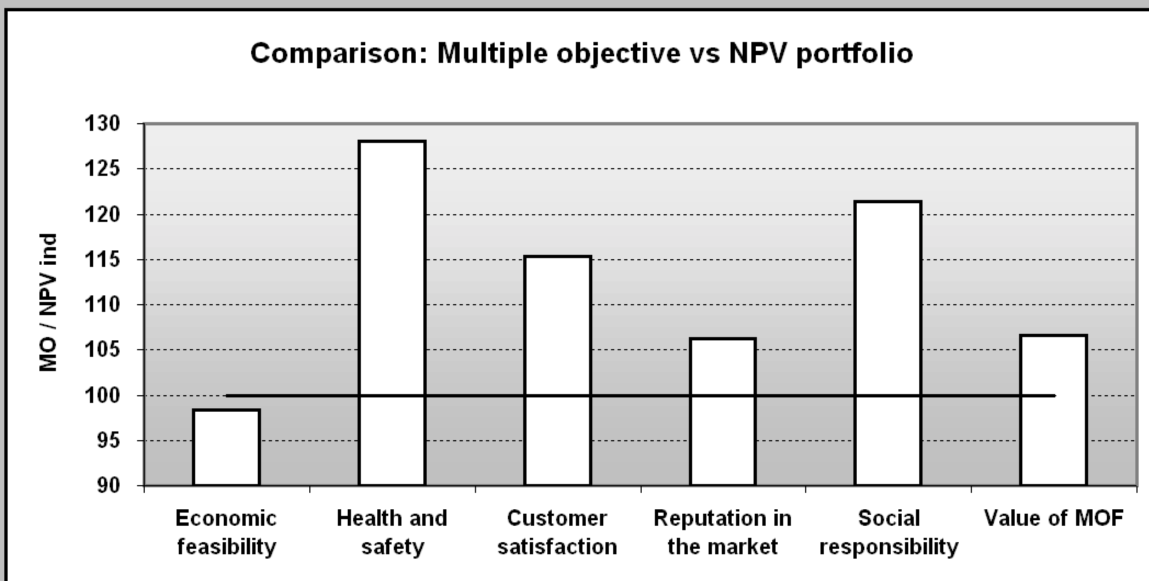
Table 54 displays the weights (as determined in Table 36) under each multiple objective of those projects that have been selected for the portfolio. By summing the weights under each objective, one gets an indication of the portfolio's support for each objective. As mentioned before, these weights cannot be expressed in any unit of measurement, but they should be viewed as relative measures and as such can be used in comparisons. Table 54 also shows the calculation of the NPV-portfolio's multiple objective score of **57.62**. To complete the comparison of the portfolios, the same analysis was done for the MOF-portfolio in Table 55.

	A	B	C	X	Y	Z	AA	AB
1				Economic feasibility	Health and safety	Customer satisfaction	Reputation in the market	Social responsibility
2	Project	Selection		60%	20%	10%	6%	4%
3	EuroShaft	x_1	0	-	-	-	-	-
4	Aston	x_2	1	4.18	10.64	1.96	6.78	8.93
5	Ultra	x_3	0	-	-	-	-	-
6	Sabie	x_4	1	0.27	4.26	9.80	-	3.57
7	Hertz	x_5	1	11.14	-	1.96	5.08	7.14
8	Bank	x_6	1	1.09	-	9.80	5.08	5.36
9	Discover	x_7	0	-	-	-	-	-
10	Namaqua	x_8	1	5.54	4.26	1.96	3.39	-
11	Landmax	x_9	1	3.37	10.64	1.96	8.47	7.14
12	Brakflow	x_{10}	0	-	-	-	-	-
13	Fourport	x_{11}	1	10.05	10.64	3.92	3.39	1.79
14	Extrema	x_{12}	0	-	-	-	-	-
15	LevelOne	x_{13}	1	6.15	4.26	9.80	6.78	7.14
16	Hever	x_{14}	1	4.23	10.64	3.92	5.08	7.14
17	Castle	x_{15}	1	3.73	8.51	7.84	6.78	7.14
18	Kwasand	x_{16}	0	-	-	-	-	-
19	Terminate Namaqua	x_{17}	0	-	-	-	-	-
20	Terminate Landmax	x_{18}	0	-	-	-	-	-
21	Terminate Brakflow	x_{19}	1	2.81	-	1.96	3.39	1.79
22	Terminate Fourport	x_{20}	0	-	-	-	-	-
23	Terminate Extrema	x_{21}	1	3.63	2.13	1.96	1.69	1.79
24	Terminate LevelOne	x_{22}	0	-	-	-	-	-
25	Terminate Hever	x_{23}	0	-	-	-	-	-
26	Terminate Castle	x_{24}	0	-	-	-	-	-
27	Terminate Kwasand	x_{25}	1	3.83	2.13	1.96	1.69	1.79
28	Portfolio Total =			**60.04**	**68.09**	**58.82**	**57.63**	**60.71**
29								
30				Value ot the portfolio's Multiple objective function =				**61.41**

Table 55: Analysis of the MOF-portfolio in terms of the company's multiple objectives.

Table 56 shows the comparison of the two portfolios in table and graphic form.

	NPV portfolio	MO portfolio	MO difference to NPV
Economic feasibility =	61.05	60.04	-2%
Health and safety =	53.19	68.09	28%
Customer satisfaction =	50.98	58.82	15%
Reputation in the market =	54.24	57.63	6%
Social responsibility =	50.00	60.71	21%
Value of MOF =	**57.62**	**61.41**	**7%**
NPV (R m) =	**2,181**	**2,146**	**-2%**



<u>Table 56:</u> Comparison of the multiple objective and the NPV portfolios

The graph in Table 56 presents the comparison in terms of a MO / NPV index that is calculated for each objective as follows:

$$MO\ difference\ to\ NPV = \frac{MO\ score}{NPV\ \ score} - 1$$

The main conclusion that can be made from this comparison is that even though the MOF-portfolio generates a NPV which is R36m less that the NPV of the NPV portfolio, it recommends a portfolio that support the company's other objectives to a much greater extent. The basis of comparison above indicates a 2 % drop in NPV, but a 28% increase in Health and safety, a 15% increase in Customer satisfaction, a 6% improvement in the company's reputation in the market and a 21% improvement in respect of social responsibility.

Company management can now decide whether the increased support of the company's other objectives justifies the 2% drop in NPV.

4.9 Portfolio risk analysis

The objective of this section is to determine the portfolio's risk and to compare it with the company's risk threshold. The company has put a risk threshold of 10% on the portfolio of projects. It means that the probability that the portfolio of projects generates insufficient returns (or that the NPV of the portfolio is negative) should be less than 10%.

The following two methods of determining portfolio risk have been described in section 3.7:

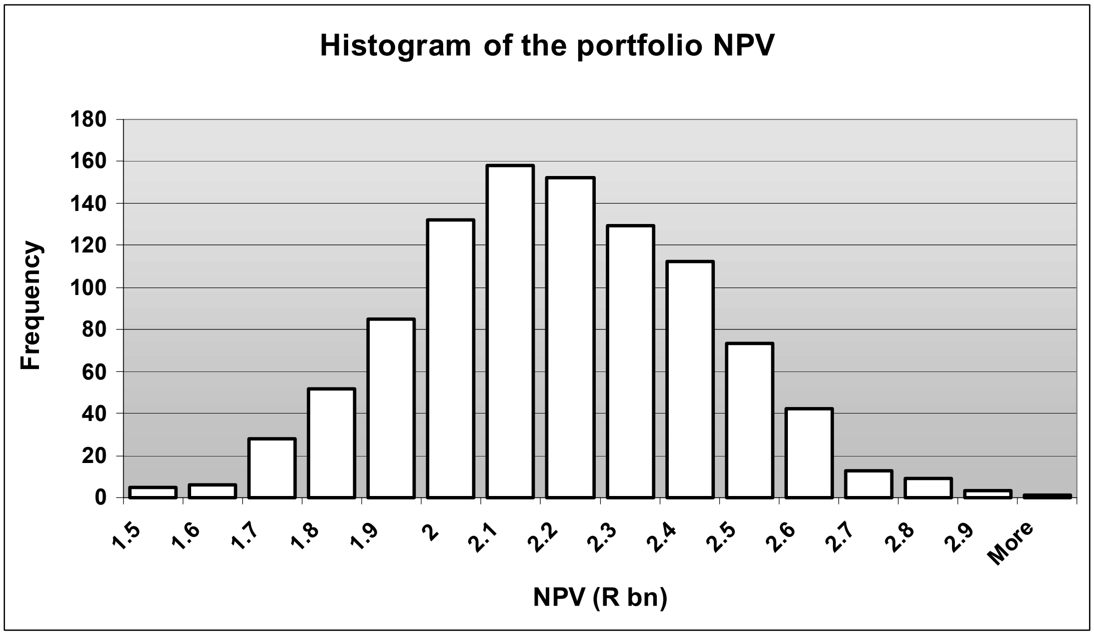
- Monte Carlo simulation.
- Portfolio variance formula.

Monte Carlo simulation

The Monte Carlo simulations on the individual projects were done on a consistent basis, which means that the set of parameters that are common to all the projects (e.g. exchange rate, inflation) were applied to all the projects in each run, but were allowed to change according to their distributions from run to run. This effectively means that each simulation run represents a feasible scenario of the future and reflected the performance of the different projects under the different scenarios. By simply adding the simulation results of the projects selected for the portfolio, one gets a set of simulation runs for the portfolio of projects.

Figure 20 shows a histogram of the simulation runs on the portfolio of projects. The following results were also calculated:

- Standard deviation of the portfolio's NPV = R239m.
- Number of negative NPV's in the 1,000 simulation runs = 0.
- Minimum NPV = R1,407m
- Maximum NPV = R2,976m.



<u>Figure 20:</u> Histogram of the portfolio NPV-values

One can therefore conclude from the simulation results that the portfolio risk is negligible.

Portfolio variance formula

One can also apply the portfolio variance formula described in section 3.7. By comparing the projects' outcomes in the 1,000 simulation runs, one can calculate the correlation coefficients between the projects (see Table 57). With each project's expected NPV and standard deviation, one can apply the portfolio variance formula. This was done for Freesia Industries and the standard deviation for the portfolio's NPV was calculated as R234m, which is very similar to the standard deviation of R239m, as determined from the Monte Carlo simulation runs.

	EuroShaft	Aston	Ultra	Sabie	Hertz	Bank	Discover	Namaqua	Landmax	Brakflow	Fourport	Extrema	LevelOne	Hever	Castle	Kwasand	Terminate Namaqua	Terminate Landmax	Terminate Brakflow	Terminate Fourport	Terminate Extrema	Terminate LevelOne	Terminate Hever	Terminate Castle	Terminate Kwasand
EuroShaft	1.00	-0.00	0.05	-0.01	-0.03	-0.01	0.00	0.06	0.01	-0.02	0.03	-0.03	0.02	0.04	-0.02	0.02	0.02	-0.01	0.01	-0.02	-0.00	-0.07	0.02	0.01	-0.04
Aston		1.00	-0.05	-0.02	-0.03	0.01	0.02	-0.04	0.00	-0.02	-0.03	0.00	-0.01	-0.02	-0.00	0.05	0.01	0.01	0.01	-0.03	-0.02	0.02	-0.03	-0.01	-0.04
Ultra			1.00	-0.00	-0.01	-0.04	0.05	0.06	-0.01	0.01	-0.05	-0.01	-0.00	0.01	0.00	0.02	0.01	0.01	-0.02	0.00	0.05	0.04	-0.06	0.00	0.00
Sabie				1.00	-0.01	0.04	0.01	0.04	0.00	0.03	-0.00	-0.00	0.04	0.05	-0.02	0.05	-0.03	0.01	0.03	0.02	-0.00	0.02	-0.04	0.04	-0.03
Hertz					1.00	-0.05	-0.03	0.01	-0.07	0.00	-0.00	0.04	0.02	0.00	0.03	-0.07	0.03	0.02	-0.01	-0.03	0.01	0.01	-0.02	0.04	-0.04
Bank						1.00	-0.04	-0.01	0.00	0.01	-0.02	-0.02	-0.01	0.05	-0.01	-0.03	-0.01	-0.04	-0.06	-0.01	-0.01	0.02	0.01	0.02	0.01
Discover							1.00	0.01	-0.03	0.01	-0.01	0.04	-0.01	0.03	-0.03	0.05	-0.04	-0.04	0.02	-0.01	-0.06	-0.00	0.01	0.07	-0.03
Namaqua								1.00	-0.01	-0.02	-0.01	-0.01	0.07	0.01	-0.02	-0.05	0.04	0.04	0.03	0.05	-0.00	0.03	-0.02	0.03	-0.05
Landmax									1.00	0.01	0.01	-0.01	0.02	-0.04	-0.01	-0.01	0.03	-0.05	-0.01	-0.01	0.01	0.04	-0.01	0.02	0.02
Brakflow										1.00	-0.00	-0.00	0.08	0.01	-0.01	0.01	0.04	-0.08	-0.01	0.00	0.05	0.02	0.02	0.03	-0.03
Fourport											1.00	-0.04	-0.01	-0.02	0.03	-0.01	-0.03	0.03	-0.00	-0.01	-0.00	-0.04	-0.02	0.03	-0.01
Extrema												1.00	-0.01	0.04	-0.01	-0.05	-0.02	0.06	-0.02	-0.03	-0.00	0.02	0.02	-0.01	-0.01
LevelOne													1.00	-0.05	0.02	0.00	0.01	-0.02	-0.01	0.07	0.06	0.01	-0.02	-0.03	-0.02
Hever														1.00	0.02	-0.04	0.03	-0.01	-0.02	-0.00	-0.02	-0.05	-0.02	0.00	-0.04
Castle															1.00	0.05	0.01	0.01	0.03	-0.02	0.03	0.05	-0.00	-0.04	-0.02
Kwasand																1.00	-0.01	-0.08	0.04	-0.04	0.03	-0.01	-0.00	-0.05	-0.00
Terminate Namaqua																	1.00	0.02	-0.02	-0.03	0.01	-0.04	0.02	-0.02	-0.01
Terminate Landmax																		1.00	-0.04	0.05	-0.01	-0.01	-0.02	0.01	-0.03
Terminate Brakflow																			1.00	0.01	0.06	-0.06	-0.03	-0.02	-0.02
Terminate Fourport																				1.00	0.03	0.09	-0.03	0.01	-0.02
Terminate Extrema																					1.00	-0.03	0.02	-0.06	-0.02
Terminate LevelOne																						1.00	0.03	-0.00	-0.01
Terminate Hever																							1.00	-0.02	-0.01
Terminate Castle																								1.00	-0.04
Terminate Kwasand																									1.00

Table 57: Project correlation coefficients

Portfolio risk analysis in the model

In the above example, the portfolio risk analysis was done after the optimal portfolio has been selected. It is however possible to integrate the portfolio risk analysis into the model so that the optimal solution is recommended after the optimization program ensured that the risk of the portfolio is within the company's risk threshold.

Integrating the risk analysis into the optimization program greatly increases the complexity of the model and the calculation time. The model was set up this way, but the capacity of the available version of What'sBest was not sufficient for the calculation. A working integrated model was set up but only with a limited number of simulation runs, which proved that the integration will work with the appropriate version of the What'sBest program.

4.10 Portfolio management

The development of this integrated model should not be seen as a once-off task with the aim of finding the optimal portfolio. Once the optimal portfolio has been identified the model should be maintained and should be used on a regular basis to identify when changes to the portfolio are required.

More specifically, the model should be updated when changes such as the following take place:

- **Strategic:** Strategy changes can reflect in numerous ways in the model. On a high level, the company may decide to alter its multiple objectives, whether by adding new or removing current objectives, or by changing the relative importance of the objectives. Also, with more knowledge and better judgement, the company may decide to change its assessment of certain projects in respect of certain objectives. Both these changes will result in adjusted multiple objective scores for all the projects and therefore new recommendations regarding the ultimate portfolio of projects. It remains a very important requirement that the parameters in the model should always accurately reflect the company's strategy.

- **Financial:** Changes in the company's financing structure must be incorporated in the model. Such changes can affect important parameters such as the capital availability for investment in projects and also the company's cost of capital and therefore the minimum acceptable rate of return (MARR), used in the calculation of the projects' net present values.

- **Economic:** Since many of the parameters are derived from the macroeconomic model, it is important to ensure that this model remains reliable. Any fundamental changes in the economy (e.g. exchange rates, inflation, business cycles, etc.) may result in changes to the macroeconomic assumptions, which in turn may result in changes to the optimal portfolio.

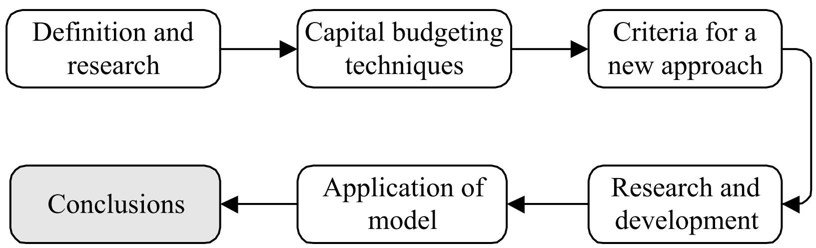
- **Changes in the industry:** Changes in a company's industry might require updates of many assumptions in the model (e.g. introduction of new and substitute products might alter demand patterns; the introduction of new technology and new manufacturing processes might change the assumptions regarding the cost of production; changes in the demand and supply of raw materials can affect prices; etc.). All such changes may alter some assumptions in the model, which can result in changes to the optimal portfolio.

- **New projects and opportunities:** Instead of simply assessing the economic merit of new projects in isolation, this model provides the company with the ability to assess the project's merit both in terms of the company's multiple objectives and in comparison with the merits of all the other existing and new projects. The introduction of new projects will therefore mean new decision variables and possible project interrelationships, which might lead to changes in the optimal portfolio.

The model's ability to accommodate changes such as those described above and to indicate whether and what changes are necessary for the portfolio to remain optimal, is a powerful feature. Such recommendations can only be seen as input to the decision-making process, where management still has the ultimate say.

CONCLUSION

The objective of this chapter is to conclude with the key aspects of this research and to comment on the potential application of this research. Figure 21 highlights this objective in relation to the overall approach for the dissertation.



<u>Figure 21:</u> The objective of chapter 5 in relation to the overall approach for the dissertation.

The fundamental proposition of this dissertation is that superior capital budgeting solutions can be attained by not only analyzing projects individually but rather as part of a portfolio of projects that has the objective of maximizing the company's range of multiple objectives, not only the economic benefit.

Some of the key aspects are the following:

i) <u>Optimization in terms of the portfolio:</u> By following a portfolio approach, the company ensures that all capital budgeting decisions are taken after full consideration was given to the whole portfolio of capital projects (both the existing and the new projects).

ii) Integrated model: The portfolio approach requires an optimization model that integrates the assumptions, constraints and analyses of all the projects into one model.

iii) Optimization programs: The availability of optimization programs that easily integrate with spreadsheets, makes it very easy to develop an integrated model.

iv) Portfolio objective: The dissertation proposes the development and use of a multiple objective function that accurately reflects the importance of all the objectives that are important to a company. The optimization program selects that portfolio of projects that maximizes value to the company in terms of this multiple objective function. Whereas this portfolio might not produce the highest economic benefit, it was shown that it is superior in terms of promoting the company's multiple objectives.

v) Economic decision criterion and risk analysis: The dissertation proposes the use of net present value (NPV) as the criterion for economic feasibility. It is proposed not to include a risk margin in the discount rate, but to rather explicitly determine each project's risk profile through Monte Carlo simulation.

vi) Portfolio risk analysis: Since the model has integrated the analyses of all the projects, one can easily determine the portfolio risk by analyzing the Monte Carlo simulations of all the projects included in the portfolio. Portfolio risk can also be determined with the portfolio variance formulae.

vii) Model development and maintenance: To integrate all the company's capital projects into such an integrated model, will require a lot of time and effort. However, once it is properly developed, its output can be most valuable and, if properly maintained, it can be used on a regular basis to ensure optimality of the portfolio of projects.

viii) Portfolio management: If the model is properly maintained in terms of keeping all the assumptions and the relationships between variables and projects current, it is easy to re-run the model when circumstances change to determine the changes that are required in order to keep the portfolio optimal.

An aspect that can be researched in more depth is the application of techniques such as sensitivity analysis in order to establish the ranges of the various parameters for which the proposed solution will still be optimal. This information will indicate the robustness of the solution or it might indicate where assumptions regarding certain variables must be reviewed. A further area of research can be the application of this approach to other decision-making situations, such as mergers and acquisitions, supplier selection strategies, equipment maintenance and replacement strategies, etc.

The value of the model lies in the benefits that the integration of the various techniques and approaches offers. The development of a multiple objective function provides the company with a tool that optimizes its choices regarding capital projects in terms of all the objectives that are important. The model thereby enables to company to make decisions after taking into account its impact on the whole portfolio of projects. By developing this model, a company can definitely improve the analysis required before capital budgets are finalized. In its totality, the model will especially be useful in situations that are characterized by a great number of projects, complicated project and variable interrelationships, many constraints and uncertainties.

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