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An R&D options selection model for investment decisions

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Abstract

Technology centered organisations must be able to identify promising new products or process improvements at an early stage so that the necessary resources can be allocated to those activities. It is essential to invest in targeted R&D projects as opposed to a wide range of ideas so that resources can be focused on successful outcomes. Typically, a number of options and tradeoffs are encountered; the selection of the most appropriate projects is the aim of R&D selection models. Although capital budgeting and financial portfolio management offer a similar style approach, the techniques used for the solution of those is different to that used for R&D project selection. The reasons for this are that project selection is complicated by many factors, such as uncertainty, interrelationships between projects, changes over time and success factors that are difficult to measure. Thus, a mathematical optimisation approach in isolation is not practical. Project selection models not only have to consider these problems but also that there are different types of R&D. The spectrum of R&D ranges from low budget exploratory research to large budget product development. This paper reviews the development of a project selection and evaluation tool that can be applied to a wide range of research, technology and investment decisions. Firstly, the background on project selection models is given. This is followed by the introduction of the model and its application to a sample group of projects. Finally, some conclusions are discussed as to the applicability of such models.
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1. Selection model usage

Most organisations use some form of project selection/justification tool, which, according to Liberatore (1987) is usually one of the standard financial analysis methods, such as cost–benefit analysis or discounted cash flow. Techniques such as mathematical programming are not widely used due to the diverse nature of the projects. A wide variety of project selection models have been assembled over the years, including linear programming, scoring models and checklists. Many early selection models were based on an optimisation approach. Given a number of projects and a pool of resources, the portfolio of projects was optimised to a certain criterion. This usually involved the conversion of the attributes of a project into a single monetary value. There is little information on the application of these early models to project selection decisions. For R&D type selection decisions, Moore and Baker (1969) suggested that the models were not entirely suitable due to a lack of input data. The complexity of the models and the problems of application can be a deterrent.

The fact that models were not being used was summed up by Moore and Baker (1969): "Management is not likely to use any model in deciding between projects, the use lies in the range of information generated for making selection decisions". In other words, the process of gathering the information was perceived as the main function of the model. Schmidt and Freeland (1992) describe traditional optimisation processes as "classical" models, where the focus is on the outcome. "Decision event" or "systems" models focus on the process by which the outcome is reached. The result of a systems approach is that the information generated in applying the model is used in the subsequent decision making. An improvement on the classical type of model, and a direction of subsequent research, was "Multiattribute Utility Theory" (MAUT), of which an overview is given by Pearson et al. (1996). Individual projects are rated on different merits using processes such as scoring models or checklists. Rather than

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having a single constraint to which the project portfolio is optimised, MAUT encompasses a number of different areas, such as risk, reward and resource allocation amongst others.

Recently, studies of applications of models have concluded that the models do work. A survey by Cooper et al. (2001) on the uses of portfolio management models concluded that using some form of portfolio selection tool or system is greatly beneficial. These benefits included a better balanced and aligned portfolio. Farrukh et al. (2000) present a workshop approach to the problem of the design and application of a selection method. The involvement of multidisciplinary teams in the sessions enables a broad view of the problem and the application of more than one evaluation method. Findings by Cooper et al. (2001) showed that those that use more than one selection method have the best results, since no single method has the best attributes in all areas. It appears that the trend in applying selection models is to move away from the application of a single method and to move towards a composite approach of using a number of selection methods. Those criteria that produce effective programmes involve information on markets, customer needs, competitors and regulatory and environmental concerns (Adler et al., 1992). Incorporation of these factors into a selection method hints at the use of a composite model.

Pearson et al. (1996) argue that the process of project selection has given way to project evaluation. Rather than having an R&D budget and a pool of projects, the situation has become one of ensuring that the corporate requirements of the R&D function are met. This not only includes the initial evaluation of projects, but also continual review throughout their lifespan. The Stage Gate™ system of Cooper (1986) is a way to provide a frame for the constant evaluation of projects from initial idea to product launch. The idea is that at each stage of a project's life it is assessed. This can be in the form of a go/kill decision. This stage gate process was expanded by Cohen et al. (1998) to include basic research projects by adding an extra gate to the beginning of the process. A scoring model was used as the method of assessment.

2. New model

The model introduced in this paper has been developed by Lockwood (1999). The present study represents an extension of that work through a trial application to a sample group of projects; a flow diagram of the model is shown in Fig. 1.

Cooper et al. (1998) conducted surveys on the use of selection models in companies and found that the top 20% used business strategy to allocate resources. Although many used financial methods dominantly, these were found to have the worst performing portfolios. Other methods in use were strategic approaches, financial methods, scoring models and bubble diagrams. The conclusions of these surveys were that the best approach to portfolio management is the concurrent use of several selection methods. When faced with a project selection decision, the decision maker is faced with a vast amount of information and conflicting requirements. The incorporation of all these into a single selection model would result in it being overly complicated and practically impossible to use. As a result, any model must be a simplification of reality; therefore the most basic requirements of a project selection tool are as follows:

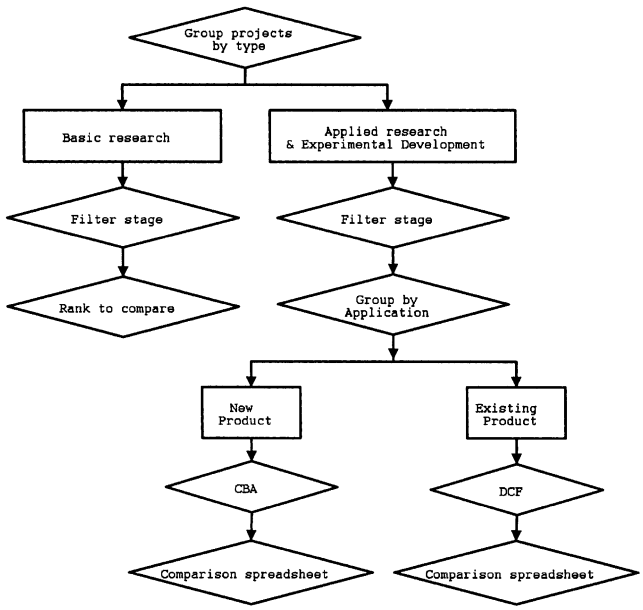

Fig. 1. Selection model flow chart.

- Project evaluation—examination of single projects to establish whether they are worth conducting.
- Project selection—examination of a range of projects to obtain an attractive portfolio.
- Application to the different types of research.

This range of requirements necessitates a multiattribute approach, since no single analysis method is applicable to all types of research. The most appropriate way to incorporate a number of different selection methods into one model is through a staged filtering approach. This allows unpromising projects to be discounted at an initial stage before much effort is spent.

3. Stages of the model and their applicability to the different types of research

3.1. Grouping stage

One of the most important aspects of project evaluation is that the evaluation tool should be suitable for use on that particular type of project. Although there are no clear cut definitions of the different types of R&D, there are some areas into which R&D activities can be grouped. This classification of R&D then allows the application of the most appropriate tools. Three broad areas can be defined,

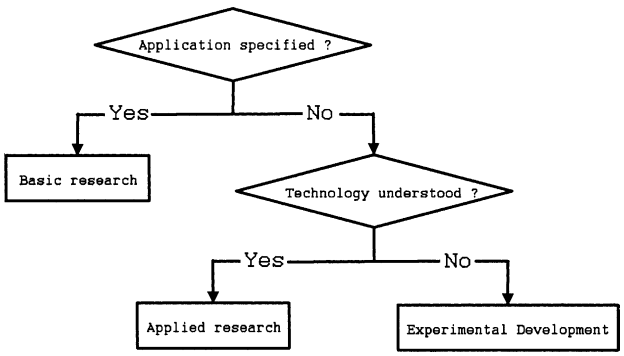

Fig. 2. Chart to assist in the classification of projects.

according to OECD (1981) and Tidd et al. (1997):

1. Basic research
2. Applied research
3. Experimental development

Each area has its own properties, such as costs, timespan and funding source. Fig. 2 shows a method of grouping projects so that the most appropriate analysis method is used.

3.2. Filter stage (evaluation)

Scoring models provide the means to evaluate a wide range of projects. The basis of scoring models is to judge a set of projects against a set of criteria to produce a project score. Different weightings can be applied to each criterion according to its relative importance. The main inputs to the scoring model then become:

- Determining the criteria
- Determining the weights
- Assigning the scores

The main benefit of the scoring model is its ability to include both qualitative and quantitative data. This is particularly applicable to R&D activities at the lower budget end, where the evaluation of projects on purely economic grounds is of little to no benefit. Scoring models are also applicable to applied research and experimental development projects. From a company survey, Cooper et al. (1999) found that 37.9% of the businesses employed a scoring model and that they yielded projects of high value.

3.2.1. Determining the weights and scores

Determining the weighting and scores is a subjective process that depends as much on personal opinion as hard numbers. Henrickson and Traynor (1999) suggest that scores and weightings should be determined using a technique such as Delphi or peer review, or a less formal method such as a questionnaire or meeting to lead to reduced biasing of the results. It is here that the workshop approach of Farrukh et al. (2000) can provide useful input.

3.2.2. Scoring table layout

The scoring model is arranged so that for each input project there are a number of categories and within each category there are a number of criteria. Interdependence between the criteria is then accounted for by applying weightings to the scores. So that there is no biasing towards a particular project or category, the total weighted scores in each case are normalised by the total weight, as depicted by Eqs. (1) and (2).

$$\text{Projectscore} = \frac{\sum_{n}^{1} \text{categoryscore} \times \text{categoryweight}}{\sum_{n}^{1} \text{categoryweight}} \quad (1)$$

$$\text{Categoryscore} = \frac{\sum_{m}^{1} \text{criterionscore} \times \text{criterionweight}}{\sum_{m}^{1} \text{criterionweight}} \quad (2)$$

where n is the number of categories and m is the number of criteria.

An example of the layout of the scoring stage is shown in Table 1. This tabular format is easily implemented in a spreadsheet. One of the disadvantages inherent in the scoring model is that it is thought of as being considerably less accurate (Moore and Baker, 1969). Much of this appears to arise from the lack of formality in applying the model. Additionally, the simplicity of the model may be a deterrent in that it can be thought of as being less scientific and too subjective. Through application of the method proposed here, an element of rigour is introduced into the scoring model.

3.3. Selection stage

Whilst the filtering stage gives an indication of the attractiveness of undertaking a particular piece of research, some quantifiable indication of the risks involved in undertaking a project, and the rewards associated with those risks, is required. The result of the selection stage is therefore designed to be a risk/reward assessment. The output of such an assessment could typically be a bubble diagram.

3.3.1. Basic research

Basic research projects are often small forays into potential new technology areas; by nature, there is little financial information. A selection system must therefore be able to support and nurture those new technologies and provide a communication of their virtues to appropriate departments. Selection decisions for projects classified as type Basic Research are aided by ranking the considered project's scores from the filter stage. Since by definition from the Project Type Classification stage no application is specified for basic research projects, it is not feasible to conduct detailed financial analysis on the merits of such projects, nor is a rigorous risk assessment deemed possible.

Table 1
Example scoring section layout

Filter	Criteria		Category		Project
	Score 1–5	Weight	Score 1–5	Weight	Score 1–5
1. Technical					
Technical risk to project completion	?	?	$S_{criterion} \times W_{criterion}$		
Technical resource availability	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
2. Corporate and strategic					
Fit with company business plan	?	?	$S_{criterion} \times W_{criterion}$		
Product range growth potential	?	?	$S_{criterion} \times W_{criterion}$		
Synergy with other products/processes	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
3. Regulatory					
Risk in obtaining regulatory clearance	?	?	$S_{criterion} \times W_{criterion}$		
Ability to meet likely future regulations	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
4. Market					
Effect on existing market share	?	?	$S_{criterion} \times W_{criterion}$		
Effect on existing market outlook	?	?	$S_{criterion} \times W_{criterion}$		
New market potential	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
5. Financial					
Commercial risk of application	?	?	$S_{criterion} \times W_{criterion}$		
Potential return on investment	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
6. Application					
Ability to implement production/process	?	?	$S_{criterion} \times W_{criterion}$		
Patentability/design protection	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
				$\sum W_{category}$	$S_{project}$

NB: Use only Categories 1–3 for projects classified as Basic Research.

3.3.2. Applied research and experimental development

3.3.2.1. Risk analysis. Risk analysis can take a number of forms, typically leading to a balancing act such as risk versus reward or cost versus safety (Crosby and Reinmann 1998). The most desirable outcome of the selection stage is a risk/reward type comparison; there are a number of ways to achieve this using one of the many risk assessment tools available. An appropriate form of risk analysis in this application is a risk based scoring model to produce a final "risk score". Table 2 shows an example of a risk analysis based on the technical, commercial and economic headings of Fahrni and Spatig (1990). Under these criteria, a project that is technically feasible, commercially sound and able to be produced/applied economically is naturally less risky.

Table 2
Example risk assessment

Risk assessment	Criteria		Category		Project
	Score 1–5	Weight	Score 1–5	Weight	Score 1–5
1. Technical uncertainty					
Inadequate technology	?	?	$S_{criterion} \times W_{criterion}$		
Not an acceptable substitute	?	?	$S_{Criterion} \times W_{Criterion}$		
Specification change	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
2. Commercial uncertainty					
Product cannot be produced economically	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
3. Economic uncertainty					
Product does not yield expected return	?	?	$S_{criterion} \times W_{criterion}$		
		$\sum W_{criterion}$	$\sum / \sum W_{criterion}$	?	$S_{category}$
				$\sum W_{category}$	$S_{project}$

3.3.2.2. Financial analysis. The well established tools of cost benefit analysis and discounted cash flow are used in the financial analysis. For those projects classified as applied research, CBA is applied. The reason for this is that there can be little accuracy in the prediction of any future cash flows, so a more approximate analysis is more appropriate. For those projects classified as experimental development, by definition a higher level of information is available, thus making a DCF analysis possible. Although DCF can account for time variation, several types of DCF are relevant for different comparison situations.

- Present Value Index (PVI) is independent of the size of the project; for example, a small project with small outflows can result in a higher PVI than a large project with large outflows.
- Internal Rate of Return (IRR) should only be used to compare projects that have similar timescales. This is because the method favours projects that have shorter payback times.
- Net Present Value (NPV) is independent of timescale, though the resulting number gives an indication of the size of the projects involved.

Considering the above, for the comparison of projects with often differing timescales and sizes, the most appropriate form of DCF would appear to be NPV.

4. Application method—an example of gas turbine project evaluation

The preceding section has introduced a project selection model that is intended to be applicable to investment tradeoff decisions. The following sections demonstrate an example application to a number of projects. Before the model could be tested, it was necessary to know what data would be available, if at all, on a range of projects. A preliminary meeting was arranged to discuss the project and the requirements. The application method then is a matter of obtaining the relevant information and carrying out the model stages. At the meeting, several of the problems of using this type of model were raised. An example is the comparison of different types of projects, i.e. basic research with experimental development. This was not considered a problem, as basic research projects are never usually compared to experimental development projects. The main reason for this is that in a large company, decisions on basic research projects are usually made from the "bottom up" and decisions for development projects are usually made from the "top down".

It became apparent that direct financial data for any product development projects would not be available. An alternative source of projects to investigate would be aftermarket products linked to the prevention of machine degradation due to fouling. This will be explained in detail in the following section. Three potential technology areas were identified as:

Table 3
Model application stages

	Activity	Section
1	Design stages	Previously completed
2	Apply scoring model	4.3
3	Apply risk model	4.4
4	Apply financial analysis	4.5
5	Evaluation	5

1. Improved air filtration
2. Gas path monitoring to identify fouling
3. Non-stick coating for the compressor blades to reduce fouling

This involved a shift in the emphasis of the project, the implications of which will be discussed. In order to apply the model, the following processes were identified to be carried out. Most of the "design stages" had already been completed by Lockwood (1999), in particular the scoring model stages.

Information was obtained through discussions with people within the company related to the areas of interest. Since inlet filtration is in use on gas turbines, more extensive information was available, particularly regarding costs. Less information was available on the newer, less common technologies of blade coatings and gas path monitoring, though manufacturers were identified who could provide some basic cost data. Once the available information had been obtained, the model was applied externally to the company with no further interaction. Table 3 shows the steps undertaken in the application of the model.

4.1. Engineering problem

Gas turbine engines are commonly used to provide a source of mechanical power for applications such as electrical power generation and offshore oil and gas pumping. The basic cycle consists of air compression, followed by heat addition and finally expansion through a turbine to produce the mechanical power output. The compressor section is composed of rotating aerofoil shaped blades whose function is to add kinetic energy to the air and then diffuse the flow so that the kinetic energy is converted into pressure energy.

Those gas turbine components that are subjected to the airflow through the machine are susceptible to fouling, which is the deposition of fine airborne particles on the surfaces. Larger particles that tend to erode the surfaces are filtered out. Because the mass flow of air through the gas turbine can be of the order of hundreds of kilograms per second, even apparently clean air can contain enough fine particles to cause fouling. Since the compressor is first in the gas path, this is where most of the fouling occurs. It has been shown that the combustor and turbine are less affected (Diakunchak, 1992). Once these deposits start to build up on the compressor blade surfaces, the blade profiles are altered

slightly, causing a change in the operation of the compressor and a loss of compressor efficiency. The result of fouling is lower mass flow and pressure rise. Although specific fuel consumption (the amount of fuel flow per unit work output) increases, the actual fuel consumption of a fouled machine decreases (Can Gulen and Paolucci, 2000) though the work output is very much less. Thus, it is uneconomical to run a machine that is fouled.

4.2. Tradeoff solutions

There are several solutions available to manufacturers and users of gas turbines. The most widely used is a filtration system at the inlet to the machine. The filtration system consists of several stages. Using increased filtration results in an inlet pressure loss, and a consequent loss of output.

4.2.1. Washing the compressor

Standard filters do not filter out the finest particles that cause degradation. The current practice to recover the performance lost due to fouling is to wash the compressor. There are various ways to wash the compressor. Online washing consists of running the machine at a low power setting and spraying a mixture of water and detergent into the compressor inlet. This does clean the initial stages of the compressor but the water and detergent will rapidly turn to steam and all the debris removed from the front of the compressor can be deposited elsewhere. Offline washing consists of stopping the machine altogether, filling it with water and detergent and turning it on the starting motor. This requires that all the bearings and entrances to the compressor are blocked or provided with backpressure so that the lubricating oil is not washed out as well. Offline washing of the compressor in this way is normally carried out in the region of 15 times per year. Not only is the actual washing process a time consuming operation, but also the machine is out of use, which in the case of electrical power generation represents a significant loss. For oil and gas producers who rely on gas turbines for pumping, there must be a standby machine, as the cost of extra machinery is a fraction of the value of the product.

4.2.2. Improved inlet filtration

All gas turbines are fitted with some form of inlet filtration apparatus, the specification of which depends on the application of the machine. For example, on offshore oil and gas applications, the filtration must cope with sea water spray. Increasing the level of filtration reduces the amount of fouling and hence the amount of washing required. However, the problem with installing extra filtration is that both capital and operating costs are increased. In addition, the filter elements introduce losses and a pressure drop at the inlet to the compressor, which results in a decreased output.

4.2.3. Non-stick blade coatings

Coatings can be applied to compressor blades in order to reduce corrosion, cracking and fouling. These coatings are usually multilayered; a base coat adheres to the blade followed by an exterior coating. Several Original Equipment Manufacturers offer the application of these coatings as an aftermarket product during the overhaul period. Claimed benefits are increased availability, reduced fouling and an increase in efficiency by as much as 3%. Further, the contaminants are more easily washed from the compressor. Costs for aftermarket blade coatings were quoted as being between £4 and £7 per blade.

4.2.4. Gas path monitoring

Fouling of the components in the gas path of the machine causes a change in the operating parameters of the various components. For the compressor, the fouling results in a decrease in pressure ratio and an increase in exit temperature. Gas path monitoring uses instruments mounted in the gas path of the machine to determine the performance of the machine in relation to the measured parameters. Changes in the measured parameters are then linked to the causes of the change, such as fouling. Thus, it is possible to determine when the compressor needs cleaning by monitoring the change in performance. This can reduce downtime as the compressor can be washed only when it is necessary.

The aftermarket nature of the products under consideration involves a change in emphasis of the model. Instead of considering only research projects that will be of benefit to the company, the projects under consideration benefit the customer more directly and the company indirectly.

One consideration is that if, for example, some of the products are used, then the machine could become more reliable and the company would generate less revenue from selling spare parts. Nowadays, though, the general trend of the manufacturers is to move towards a maintenance contract. Under this contract, the cost of repairs is borne by the manufacturer. In this case, any products that enable a reduction in maintenance costs is of benefit to both the manufacturer and the customer. Therefore, a shift in emphasis from a company research project perspective to the aftermarket products under consideration here will not affect the process of application of the model.

The application of the model to these projects was limited to the field of electrical power generation as relevant information is available. When gas turbines are used for applications such as oil/gas pipelines and pumping, the cost of the machine and fuel is minute in comparison to the cost of the product being transported.

4.2.5. Classification stage

Using the flow chart in Fig. 2, the projects have been put into their appropriate classifications such that the appropriate analysis is given. This classification is not an exact process and clearly there is some scope for opinion. The results are given in Table 4.

Table 4
Project classification

Project	Classification
Improved inlet filtration	Experimental development
Non-stick blade coatings	Applied research
Gas path monitoring	Basic research

4.3. Application of the filter scoring stage

Using the categories and criteria specified in the original model, the selection stage is applied to the projects. Some information on this level is available for all the projects. The scoring model is applied as a screening stage, to remove unpromising projects. In the case of having only a small number of projects, the scoring model can be used as a method to rank the projects according to the highest score. Results from the application of the scoring model are given in Table 5. For the application of the scoring stage, the information is obtained through questions or discussion with those who are concerned with a particular project.

4.4. Risk analysis

Since the projects are of an aftermarket nature, a basic risk assessment has been carried out in the format described previously, where a risk scoring model has been used. Scores and weightings have been set to reflect the intuitive values of lowerscore = lowerrisk. The results of the risk scoring stage are shown in Table 5. Inlet filtration, as it is already in extensive use, is naturally a lower risk option. Gas path analysis is a less well understood option, being a new technology, and therefore contains a greater element of the unknown.

4.5. Cost benefit analysis for blade coatings

Single values of cost and benefit have been calculated for the application of non-stick blade coatings. These two values are the cost of application and the benefit resulting from the manufacturer's claims for increased efficiency. Because there is no information available in the literature on links between the application of coatings and any reduction in maintenance of the compressor, it is not possible to make any benefit analysis on this area. However, based upon a quoted cost of around £6 per blade and a total of 2220 blades for a compressor, this results in a total cost of application of over £13 000. The benefits arising from this claimed 3% increase in efficiency would result in an equivalent fuel saving of the order of £25 000 per year. This results in a CBR of 1.9. Additional benefits such as not washing the compressor as often may also be gained.

Table 5
Comparison of projects

	Filters	Coatings	GPA
Scoring stage	2.92	2.68	3.49
Risk stage	1.88	3.81	3.48
DCF	0.89	•	•
CBA	•	1.9	•

• No further analysis possible at this stage.

Although the gas path monitoring project has been classified as an applied research project, insufficient information was available to carry out any financial analysis; thus, for this particular project, the model could be taken no further.

4.6. Discounted cash flow for improved filtration

Costs and benefits for improved inlet filtration have been calculated on the basis of costs and benefits to the machine user, rather than the company, as this is where the financial information is available. The calculations were based on the following assumptions:

1. Application of heavy filtration removes the need for washing the compressor.
2. Fouling of the filter causes minimal losses.

The first assumption is made due to the lack of data on the fouling of compressors with different levels of inlet filtration. The reason for this is the difficulty of carrying out any kind of controlled test, especially on an in-service machine. The second assumption is based on findings that filter fouling loss contributes to only 5% of compressor fouling losses. Assuming a five year time period (the nominal time between overhauls), a two yearly filter element replacement rate and an initial capital cost increase of £7000, the overall NPV was calculated to have a value of 0.89.

5. Final stage comparison

In this case of only having one project of each type, it is not possible to identify a "best" option. However, an idea of the attractiveness of the different projects in relation to each other is gained. Table 5 shows a summary of the results of the application with the resultant output from each section. Those stages where insufficient information was available, so that further application of the model stages was not possible, have been indicated in the table.

Inlet filtration is a fairly safe option of low risk and corresponding low reward, being a fairly well established technology. Blade coatings, whilst they do not offer protection to the entire gas turbine, do offer some monetary benefits if the manufacturer's claims are justifiable. This makes them a higher risk option. The scoring model section is straightforward to apply, but the inputs (criteria, scores and weights) need to be chosen carefully. Greater benefit can be derived from the scoring model by using a method

such as Delphi to determine the inputs. Information availability does not present a major problem to the scoring model, due to the qualitative nature of the inputs. The main benefit of the scoring model is that it can contribute to decisions concerning all the types of R&D investments.

Using some form of scoring model for the risk analysis has the benefit that the resulting number may be used in a risk–reward type of calculation. The risk analysis presented here represents basic risk identification. This does not prevent a more in-depth risk analysis being used, such as an event tree, provided the output can be quantified with an overall risk factor or risk number.

Cost benefit analysis relies very much on the scope and quality of the input data, although CBA allows a good initial indication of the financial viability of the project. Discounted cash flow, similar to CBA, relies on the quality of the input data, but to a greater extent. For large development projects, generally this type of information is available; for smaller projects, "finger in the air" guesswork to produce the inputs will not give reliable outputs.

Ideally, a selection model would collate results and enable optimisation. That is, a number of projects are input into the model as a black box and an optimum choice appears at the other end. The word optimisation implies some mathematical rigour, which is not inherent in this model, in part due to the non-mathematical aspects of the model and in part due to the diverse nature of the input projects.

6. Summary

The model has been applied to a group of R&D projects to provide a basis upon which to evaluate it. This has consisted of the processes of designing the stages, gathering the required information and applying the stages. The intention of the model is to compare like with like and be applied to different types of R&D projects.

Generally, within large organisations there are formal decision making processes, which, for the selection of major investment projects, usually involve undertaking a business case study. Using the business case as a lever, the management can decide on the best course. The range of information contained in the business case is vastly more than can be incorporated into a selection model. Despite this, for small to medium projects, there is some value in using a selection model. This value is summed up below.

What it does do:

- Provides insight into the selection process—an indication of those metrics that influence the decisions is gained.
- Enables a "systems" approach—the application of the various stages has produced a wide range of information at many levels.
- Gives justification to the choice of a particular project and records the results of decisions made along the way.
- Increases the amount of information available to the decision maker.

What it does not do:

- Give an optimum project solution—the range of input projects is very diverse, making an optimisation process impractical.
- Completely remove the manager's decision—an element of human input is needed to keep watch over the procedure.

6.1. Incorporation into the stage gate process

The stage gate process of project selection was introduced earlier. One aspect of it is that as projects progress through the review process, they change in nature from being basic research projects to experimental development projects. Initial high risk, low reward projects become low risk higher reward projects by the later stages. Rather than being an alternative to the stage gate process, the model presented here lends itself to incorporation into each gate review and provides the method of assessment for making go/kill decisions. An alternative method, presented by Cooper et al. (1997), uses a portfolio review alongside the stage gate process. The portfolio review is used to assess the entire portfolio of the company to ensure that the correct mix of projects is present.

6.2. Conclusions

The benefits of using the model presented here are a formal decision structure and communication of information about projects. The additional benefit of extending the process to include basic research is gained. The application of such a model does require more work, and hence more cost, as although the information needed may exist, it must be collected and arranged. From this study, it appears that the role of the selection model is more relevant to lower budget R&D projects, where little or no structured decision making is used. This might be the evaluation of basic research projects within large companies, for example. Through the concurrent application of several types of selection methods, business strategy in addition to financial methods aids the decision making process. The model allows a step-by-step approach incorporating a number of sources of information. Although all of the individual pieces of the model are in use and exist as selection methods in their own right, bringing them together in a framework allows the positive features of each to be used. It is suggested that models such as this be applied using this framework approach which allows flexibility for selection decisions within different industries.

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