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A METHODOLOGY FOR THE SELECTION OF NEW TECHNOLOGIES IN THE AVIATION INDUSTRY

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Abstract

The purpose of this report is to present a technology selection methodology to quantify both tangible and intangible benefits of certain technology alternatives within a fuzzy environment. Specifically, it describes an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations for utilisation in the industry. The report proposes a complete methodology to accurately select new technologies. A computer based prototype model has been developed to handle the more complex fuzzy calculations. Decision-makers are only required to express their opinions on comparative importance of various factors in linguistic terms rather than exact numerical values. These linguistic variable scales, such as 'very high', 'high', 'medium', 'low' and 'very low', are then converted into fuzzy numbers, since it becomes more meaningful to quantify a subjective measurement into a range rather than in an exact value. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. This deals quantitatively with imprecision or uncertainties, as the cash flows are modelled as triangular fuzzy numbers which represent 'the most likely possible value', 'the most pessimistic value' and 'the most optimistic value'. By using this methodology, the ambiguities involved in the assessment data can be effectively represented and processed to assure a more convincing and effective decision-making process when selecting new technologies in which to invest. The prototype model was validated with a case study within the aviation industry that ensured it was properly configured to meet the industry's specific requirements.

Keywords: *Technology Selection, Hierarchical Structural Analysis, Multi-Criteria Decision-Making, Triangular Fuzzy Numbers*

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1. Introduction

Aviation companies invest millions of pounds each year into the development and implementation of new technologies for use in the aircraft and within the associated manufacturing processes. It is becoming increasingly difficult to clarify the right technology alternatives. This is mainly because the number of available technologies is increasing and these new technologies are containing increasing amounts of complexity. However, the correct selection of technologies could create significant competitive advantage and ensure that in such a cutting edge industry that a company remains successful.

This report was produced following a project carried out in partnership with an aviation subsidiary company. This company has a high level of interaction with new technologies. Whilst the company has guidelines on how a technology is developed once selected, at the outset of the research it was unclear how new technologies for projects were selected due to the lack of a defined methodology for this process. This report aims to address this problem by providing a methodolgy for dealing with a situation where there are a number of possible new technologies available for selection. The methodolgy also provides a means of recording the reasons behind the selection decision. The main objectives of the research were to obtain a deeper understanding of the key criteria for selecting new technologies and to develop a methodology that would define how to measure the different technology options against these criteria so that they can be compared to facilitate the decision-making process.

1.1. Scope Of The Report

The term 'new technology' needs to be characterized in order that the scope of the report can be defined. Due to the very broad nature of the term 'new technology', it would be infeasible to expect the report to address all the different types of selection procedures that would be necessary for all types of new technology. Initial research has shown that there are two parts to the definition. Firstly, defining what is 'new' and secondly, defining what is the 'technology' that is new. There are three classifications of the term 'new' which are; new to mankind, new to the industry and new to the company. There are two forms of new 'technology'; a new design concept that is developed to become a product or a new manufacturing process.

This report has concentrated on new technologies that are either new design concepts or new manufacturing processes within the field of fighter jet transparencies that are only new to the company. The reasons for this decision was firstly because the methodology of new technology selection should be generic enough to be able to compare any type of technology, it just happens that fighter jet transparencies is the field in which the sponsoring company works. Secondly, despite the methodology being able to deal with uncertainty it can only be realistically applied when there is enough information known about the possible technologies to be able to at least make an educated guess of certain criteria for comparison.

2. Challenges In New Technology Selection

Specific problems have been encountered with the selection of new technology for development, be it technology new to the world or merely new to the industry. Here the aviation subsidiary company may not have the necessary experience, practical 'know how', the correct development life cycles, resources or the application techniques in place to develop the technology. Thus it has proved extremely difficult to answer key questions such as: 'How many development loops are needed before an acceptable solution is reached?'

The answers to such questions could be more easily found if a methodology was followed during the selection of new technologies that accounted for all of the above issues and more. Such a procedure could also have an additional benefit that even if a project fails, every step of the selection process would have been recorded and so the reasons behind certain key decisions could be evaluated and the lessons learnt from any mistakes.

In the aviation subsidiary company, any new product within the military transparency market, where performance is so critical and normally incorporates a number of new technologies, the risks in the selection of the correct technology and ultimately the products report management can be compounded. The company working with this project has recognised that it has little in the way of formal procedures or recognised techniques and in conjunction with Cranfield University, has realised that the general aviation industry also has limited understanding of processes for the selection of any new technology.

2.1. The Importance Of Technology Selection

The term 'technology' is defined by Steele (1989) as 'knowledge of how to do things', or 'capabilities that an enterprise needs in order to provide its customers with the goods and services it proposes to offer, both now and in the future'. This leads to an aim for technology selection, which is to obtain new know-how, components and systems which will help the company to make more competitive products and services, more effective processes, and/or create completely new solutions. New technologies can also offer opportunities for both product differentiation and totally new businesses and so the importance of accurate technology selection is critical for the survival of any company. This is why a detailed methodology or systematic procedure is required that describes how to ensure all relevant information has been considered when making this critical decision.

3. Related Research

3.1. Issues In Technology Selection

Selection of new technology is one of the most challenging decisions that the management of a company encounters. Torkkeli and Tuominen (2002) address this problem with a study to provide a process that can be used to analyse and understand the links between the selection of a new technology and the core competencies of a company. The study helps to identify the priorities between the technologies and the markets whilst highlighting that opportunities for building and managing core competencies should be systematically assessed when selecting technologies. The process presented by the paper helps to clarify the impacts of technology selection on core competencies in a systematic way within industrial companies. The paper addresses the potential benefits of support system for a group deciding on the selection of new technology. The limitation of using the techniques found in this paper is that the work has not been applied to any real-life problems and therefore lacks any realistic testing of the theories. However, this recently published paper does contain some key concepts that once validated have proven useful to the research in this report.

3.1.1. Factors To Consider In Technology Selection

Yap and Souder (1993) identify several characteristics of technologies that should be taken into account in any technology selection model. These include:

- the uncertainties of commercial and technical success (risk)
- the funding history of the technologies
- the resource requirements to develop technologies
- the degree to which the technologies contribute to established projects
- the current life-cycle stage of the technologies

There can also be relationships between different technologies that must be considered. The selected technology must match the present technologies and systems of the company.

Opinions about the selection of technology alternatives and the allocation of resources should come from all levels of the organisation. In this case, according to Yap and Souder (1993) efficient communication between different experts is essential for two reasons. First, the better the parties are informed about technologies, the higher the probability that the parties will be committed to supporting the selection decision. Second, open communication facilitates the flow of informed opinions and subjective information is vital to the correct technology selection.

Fahrni and Spätig (1990) have defined many factors which should also be taken into account in the selection. These factors include concentration on the most critical problem, the degree of quantification of relevant factors, the degree of interdependencies between technologies, consideration of single or multiple objectives and the degree of risk. According to Arbel and Shapira (1986) there is a need for a systematic analysis of factors involved in the selection, considering the criteria and parameters leading to the evaluation and selection of an optimal choice. Their selection model focuses on two major groups of issues: benefit and cost. Piippo and Tuominen (1990) emphasize the match of alternatives to the capabilities and strategies of companies and risks, as major factors in the selection, in addition to benefits and costs.The four pieces of literature reviewed all contain very valid considerations and recommendations that will be referred to during this report. The limitations of these papers are that they present research that was conducted and validated in different contexts to that of this report and all the work was carried out over a decade ago.

3.1.2. Justification Of New Technology

Despite being published in the late eighties, Currie (1989) presented a paper that lays the foundations for this research. The topic of justifying new technology to senior management is an important reason for implementing any process of technology selection. The research points out that previous work on the selection and implementation of new technology has already proven that the use of traditional cost accounting methods to justify technology is outdated. This is evident in the situation where senior managers require detailed cost-benefit information to demonstrate the short and long-term returns from new technology.

Currie (1989) carried out the research from the perspective of selecting technology for the implementation of Computer-Aided-Design (CAD) systems. The main observation of the research was that managers from different departments weighted the requirements in different ways. Senior managers required a quick payback period and effective utilisation of resources, whilst engineers considered CAD systems as a "necessity investment". It is suggested that even with the divergent weighting of the requirements, managers must select technology together, as a group, in order to select effectively.

The paper also identified that decision-making on technology can be fragmented due to communication difficulties arising because those with technical skills are not given access to necessary company resources without satisfying the stringent controls imposed by accountants. It was concluded that companies where senior engineering managers were given greater powers in the disposal of company resources for new technology experienced fewer post-implementation problems, compared to those companies where progress in technological change was inhibited by short-term and traditional budgetary control systems.

3.1.3. Justification Methods

According to Meredith and Suresh (1986) investment justification methods in Advanced Manufacturing Technologies (AMT) are classified into:

- economic analysis techniques
- analytical methods
- strategic approaches

These methods deviate from each other mainly due to the treatment of non-monetary factors. Economic justification methods of manufacturing investments are discussed thoroughly by Proctor and Canada (1992). Economic analysis methods are the basic discounted cash flow techniques such as present worth, annual worth, internal rate of return and other techniques such as payback period and Return on Investment (ROI) which ignore the time value of money. The application of these techniques to the evaluation of Flexible Manufacturing System (FMS) investments is analysed by Miltenburg and Krinsky (1987). It is well known by engineering economy practitioners that accounting methods, which ignore time value of money, would produce inaccurate or at best approximate results.

When flexibility, risk and non-monetary benefits are expected, and particularly if the probability distributions can be subjectively estimated, analytical procedures may be used. Strategic justification methods are qualitative in nature and are concerned with issues such as technical importance, business objectives and competitive advantage (Meredith and Suresh 1986). When strategic approaches are employed, the justification is made by considering long-term intangible benefits. Hence, using these techniques with economic or analytical methods would be more appropriate. Figure 1, which is an updated version of the classification initially proposed by Meredith and Suresh (1986), evaluates the different justification methods for AMT.

Since certain criteria cannot be expressed in quantitative terms, a number of articles focus on integrating the qualitative and quantitative aspects to evaluate the benefits of an Advanced Manufacturing System (AMS). Wabalickis (1988) developed justification procedure based on the Analytic Hierarchy Process (AHP) to evaluate the numerous tangible and intangible benefits of an FMS investment. Naik and Chakravarty (1992) pointed out the need for integrating the non-financial and strategic benefits of AMS with the financial benefits and proposed a hierarchical evaluation procedure involving strategic evaluation, operational evaluation and financial evaluation. Shang and Sueyoshi (1995) proposed a selection procedure for an FMS employing the AHP, simulation and Data Envelopment Analysis (DEA).

Small and Chen (1997) discussed the results of a survey conducted in the US that investigated the use of justification approaches for AMS. According to their findings, manufacturing firms using hybrid strategies, which employ both economic and strategic justification techniques, attain significantly higher levels of success from advanced technology projects. Sambasivarao and Deshmukh (1995) presented a decision support system integrating multi-attribute analysis, economic analysis and risk evaluation analysis. They suggested AHP, TOPSIS and linear additive utility model as alternative multi-attribute analysis methods. Methods include game theoretical models, multi-attribute utility models, fuzzy linguistic methods and expert systems.

	Techniques	Advantages	Disadvantages
Economic	Payback method	Ease of data collection	Do not take into account strategic and non-economic benefits
	Return on investment	Intuitive appeal	Consider a single objective of cash flows, and ignore other benefits such as quality and flexibility
	Discounted cash flow techniques		
Strategic	Technical importance	Require less technical data	Necessity to use these techniques with economic or analytic ones since they consider only long-term intangible benefits
	Business objectives		
	Competitive advantage	Use the general objectives of the firm	
	Research and development		
Analytic	Scoring models (Analytic Hierarchy Process (AHP)	Uncertainty of the future and multi-objectivity can be incorporated	Require more data
	Mathematical programming		
	Integer programming		
	Goal programming		
	Data Envelopment Analysis (DEA)	Subjective criteria can be introduced in the modelling phase	Usually more complex than the economic analysis
	Stochastic methods		
	Fuzzy set theory		

Figure 1: Justification methods for advanced manufacturing technologies (Karsak and Tolga 2001)

3.1.4. Discounted Cash Flow

Discounted Cash Flow (DCF) methods appear as the most popular economic justification methodology (Karsak and Tolga 2001), though determining cash flows (revenues, expenses) and discount rates as crisp values can lead to inaccurate results in most real-life applications. The probabilistic cash flow analysis can be used if the probabilities of the possible outcomes are known. However, when the frequency distribution of the possible outcomes is not known, as for the revenues and expenses of a new product line, most decision-makers employ expert knowledge in modelling cash flows in the evaluation phase (Chiu and Park 1994; Ward 1989).

The conventional DCF methods do not appear to be suitable on their own for the evaluation of an AMS investment due to the non-monetary impacts posed by the system. Sullivan (1986) pointed out the inadequacy of traditional financial justification measures such as, return on investment, payback and net present worth, when considering the strategic merits of advanced manufacturing technologies. The results of the surveys conducted by Lefley (1994) for justification of AMT in the UK, and by Lefley and Sarkis (1997) for appraisal of AMT investments in the UK and US, both indicate the support for the difficulty in assessing AMT investments due to their non-quantifiable benefits. Due to this difficulty, over 80% of the respondents in the US and UK pointed out that not all potential benefits of AMT investments are considered in the financial justification process. Furthermore, the results of the surveys stated that subjective assessment of AMT investment with/without financial justification is observed in approximately 60% of the manufacturing firms responding to the questionnaire. Improvements in product quality, reliability, production efficiencies, competitiveness as a result of the versatility and flexibility of the system are the focal points in the justification stage of an AMS investment. Productivity, quality, flexibility and other intangibles should be examined in terms of potential returns through enhancement of long-term business competitiveness as well as in terms of a comprehensive evaluation of internal costs (Proctor and Canada 1992).

3.1.5. Fuzzy Selection Methods

The selection of an AMT is very important to a company's survival. As a result a large amount of research can be found in this field, with a variety of theories being presented. Karsak and Tolga (2001) proposed fuzzy decision-making as a method for evaluating new technologies. A procedure that evaluates AMS investments was presented. A fuzzy decision algorithm was used to select the most suitable technology considering both economic and strategic criterion. The cost or economic aspects are addressed using the fuzzy discounted cash flow analysis.

Their research presented a valuable procedure that has considered a large amount of previous work in developing its findings. The paper provides a comprehensive numerical example to illustrate the results of the analysis that could be manipulated in order to fulfil the requirements of this report. The only limitation of the work is that within the report the theory is not validated with a real-life problem. Karsak and Tolga (2001) looked extensively at all of this past work and proposed a fuzzy decision-making procedure as a computational-elective alternative to rectify some of the difficulties posed by the existing evaluation techniques.

A paper entitled 'Evaluation Methodologies for Technology Selection' (Chan *et al.* 2000), similar to the work done by Karsak and Tolga (2001), utilised Multi-Criteria Decision-Making (MCDM) in presenting a technology selection algorithm that attempted to quantify both tangible and intangible benefits within a fuzzy environment. Specifically, it described an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. From the analytical point of view, decision-makers are asked to express their opinions on comparative importance of various factors in linguistic terms rather than exact numerical values. These linguistic variable scales, such as 'very high', 'high', 'medium', 'low' and 'very low' are then converted into fuzzy numbers, since it becomes more meaningful to quantify a subjective measurement into a range rather than in an exact value. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called the fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. Since conventional engineering economic analysis involves uncertainty about future cash flows where cash flows are defined as either crisp numbers or risky probability distributions, the results of analysis may be obscure. To deal quantitatively with imprecision or uncertainty, cash flows are modelled as Triangular Fuzzy Numbers (TFN) which represent:

- the most pessimistic value
- the most likely possible value
- the most optimistic value

The algorithm presented by this paper takes the ambiguities involved in the assessment data and effectively represents and processes them to assure a more convincing and effective decision-making.

3.1.6. Fuzzy Logic And Capital Budgeting

There are also many studies which try to apply the idea of fuzzy theory to the capital budgeting problem. The study by Remer *et al.* (1993) indicated 97% of companies' surveyed use the Net Present Value (NPV) method as a tool for report evaluation. However, there are many attempts to improve the NPV method; for example, Agmon (1991) showed in his work how to make the NPV more responsive to the full set of information. Beaves (1993) has shown how to generalise the NPV formula. These works identify the area to which fuzzy logic should be applied.

Leung (1980) studied report selection with fuzzy procedures. He constructed a criterion function which had components of worth, cost and risk in the function and he assumed these three components to be linguistic variables. Values of the criterion function imply which alternative report is the most suitable for all required specifications. Ward (1989) studied fuzzy discounted cash flow analysis by computing crisp values for cash flows and then transforming the results into symmetrical Triangular Fuzzy Numbers (TFN) and he defined a fuzzy present worth and fuzzy internal rate of return of the fuzzy cash flows. Buckley (1987) has studied fuzzy present value and fuzzy future value when assuming a cash amount, interest rate and period of time to be fuzzy. He has also discussed the methods of comparing fuzzy net cash flows in order to rank fuzzy investment alternatives from the best to the worst. Chiu and Park (1994) proposed models where cash flow and discount rate for each year are specified as TFN. The approximate form of the present worth fuzzy function was suggested and a method for comparing mutually exclusive fuzzy report by using weighted method was also shown in this paper.

A thesis by Komolavanij (1995) extends previous research in engineering economy problems through the study of fuzzy cash flow analysis using equations previously proposed by Stevens (1992) and assuming that some components are TFNs with a linear relationship. The components that are investigated are:

- total capital expenditure
- total annual income
- total gross income
- depreciation amount

The thesis identifies the fuzzy components in a cash flow and proposes a model for fuzzy total cash flow analysis (Equation 1). A sensitivity analysis is performed and a methodology is presented to evaluate the model.

$$X_{mj}=(G_{mj}-C_{mj})-(G_{mj}-C_{mj}-D_{mj})T_{m}-K_{m}+L_{mj}+V_{mj} \quad (1)$$

Where X_{mj} is the net total cash flow of the technology *m* at the end of year *j*; G_{mj} the turnover of the technology *m* at the end of year *j*; C_{mj} the operating expenses of the technology *m* at the end of year *j*; D_{mj} the depreciation amount of technology *m* in year *j*; T_{mj} the tax rate of the technology *m*; K_{mj} the investment cost of the technology *m*; L_{mj} the salvage value received in year *j*; and V_{mj} is the incremental tax credit of the technology *m* in year *j*. After the fuzzy cash flow is calculated, the NPV of *m* technology can be determined by:

$$NPV_{m} = \sum_{n=0}^{j} \frac{X_{mj}}{(1+i^{n})} \quad (2)$$

Where NPV_m is the net present value of technology *m*, *i* is the discount rate and *j* is the life of a report. All the variables stated in Equations (1) and (2) are specified as triangular fuzzy numbers which represent 'the most likely possible value', 'the most pessimistic value' and 'the most optimistic value'. The calculated fuzzy NPV is then used to provide financial data for further analysis.

3.2. NASA's Approach To Technology Selection

In recent years there has been an increased concern about obtaining the maximum return from public investment. In the United States this has forced the National Aeronautics and Space Administration (NASA) to become more accountable in its evaluation of advanced technology selection. Tavana (2003) addressed this problem by developing a multi-criteria group decision-making model for evaluating and prioritising advanced technology projects. The paper evaluates the large amount of literature available on report selection models, including scoring methods, economic methods, portfolio methods and decision analysis.

Scoring methods use algebraic formulas to produce a score for each project (Lockett *et al.* 1986; Melachrinoudis and Rice, 1991; Moore and Baker 1969). Economic methods use financial models to calculate the monetary payoff of each project under consideration (Graves and Ringuest 1991; Mehrez 1988) . Portfolio methods evaluate the entire set of projects to identify the most attractive subset (Lootsma *et al.* 1990; Vepsalainen and Lauro 1988). A specific form of portfolio analysis, cluster analysis, groups projects according to their support of the strategic positioning of the firm (Mathieu and Gibson 1993). Decision-analysis models compare various projects according to their expected value (Hazelrigg and Huband 1985; Thomas 1985). Finally simulation, a special form of decision-analysis, uses random numbers to generate a large number of problems. For each problem, the simulation develops many variables and constraints. Analysts then use the model to compare various projects and pick the best outcome (Mandakovic and Souder 1985).

Analysts have used most of these models to evaluate:

- research and development projects (Coffin and Taylor 1996; Fahrni and Spatig 1990; Taylor *et al.* 1982; Weber et a 1990)
- information systems projects (Muralidhar *et al.* 1990; Santhanam and Kyparisis 1995)
- capital budgeting projects (Santhanam *et al.* 1989; Graves and Ringuest 1991; Mehrez 1988)

Recently, researchers working on report evaluation and selection have focused on multi-criteria decision models. These models have made definitive contributions to report evaluation but do not integrate the intuitive preferences of multiple decision-makers into a structured analytical framework.

As a consolidation of the previous methods and processes, NASA has created the Consensus-Ranking Organizational-Support System (CROSS) which is a multi-criteria group decision-making model that captures the decision-makers' beliefs and enhances their intuition. CROSS employs a series of intuitive and analytical methods, such as the AHP, subjective probabilities, the entropy concept, and the Maximize-Agreement Heuristic (MAH), to enhance the decision-makers' intuition in evaluating projects.

4. As-Is Model

4.1. New Technology At The Aviation subsidiary company

The reason that evaluating the level of complexity in new projects is so difficult at the aviation subsidiary company is the company's continuing interaction with new technology. This involvement with projects that contain high levels of new technology means that often less is known about a particular project at its outset than a project utilising a tested technology. Because of this fact the majority of projects undertaken by the aviation subsidiary company can contain risks that are potentially harder to define than other projects undertaken by the parent organisation. These projects involve a lot of development work for the aviation subsidiary company in partnership with the customer. The level of new technology involved in the development of a new coating for a fighter jet canopy, for example, can be new to the company and the industry but also new to the world.

The new technology being implemented at the aviation subsidiary company is not only restricted to products being produced. There is a need for the company to look at investing in new technology for the processes of making the products. For example, a new technology is already being developed by the United States Air Force (USAF) called the Next Generation Transparency (NGT). This technology is said to be capable of increasing service life to four years, reducing the parts count by 90% and reducing the acquisition costs by 80% through the utilisation of injection moulding techniques. Figure 2 illustrates the capabilities of NGT in producing eleven canopies in just one eight hour shift.

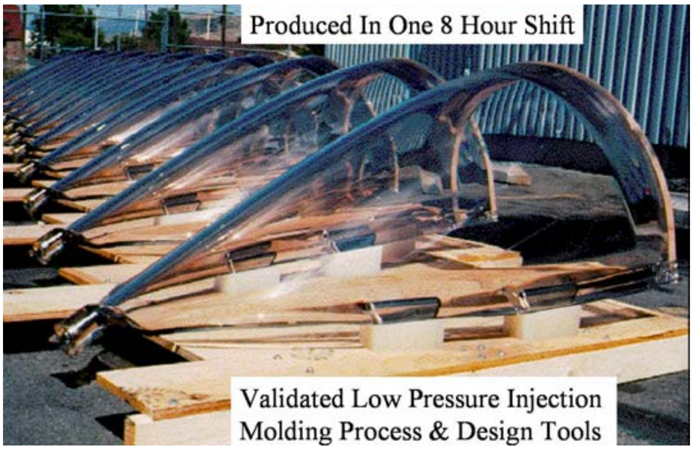


Figure 2: Canopies produced using NGT technology

4.2. New Technology Development

Currently all technology development at the aviation subsidiary company is conducted within the individual projects' timescale and budget (Figure 3). For example, the development of the coatings for the F16 fighter jet canopy utilised new technologies that were developed after the bid had been won. However, the problems with this technology development process were highlighted when the new coatings were applied and did not meet the customer's specification. This adversely affected the project's timescales and emphasized the increased risks of developing new technologies within the development of a product.

Impounding the problem is the need to remain competitive and so the estimate for development work for a new technology is usually limited to a single iteration. This is very rarely the case, as was seen with the F16 project, with the extra costs and time delays of development having to be taken on by the company through further negotiations with the customer, which is not very good for client satisfaction.

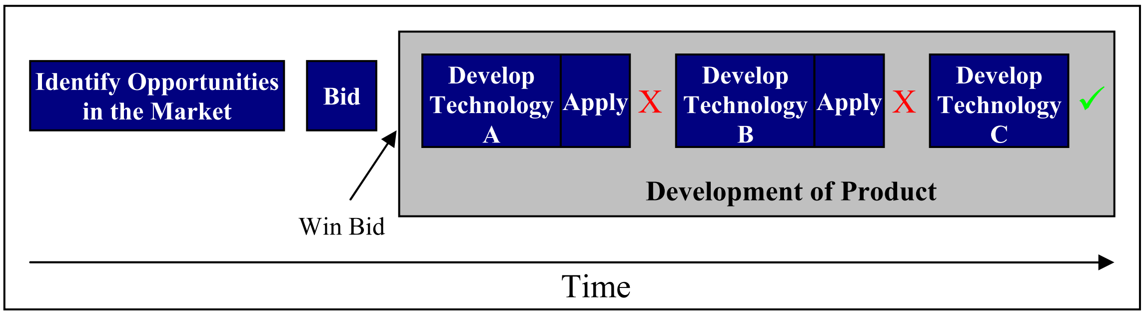


Figure 3: Current method of new technology development

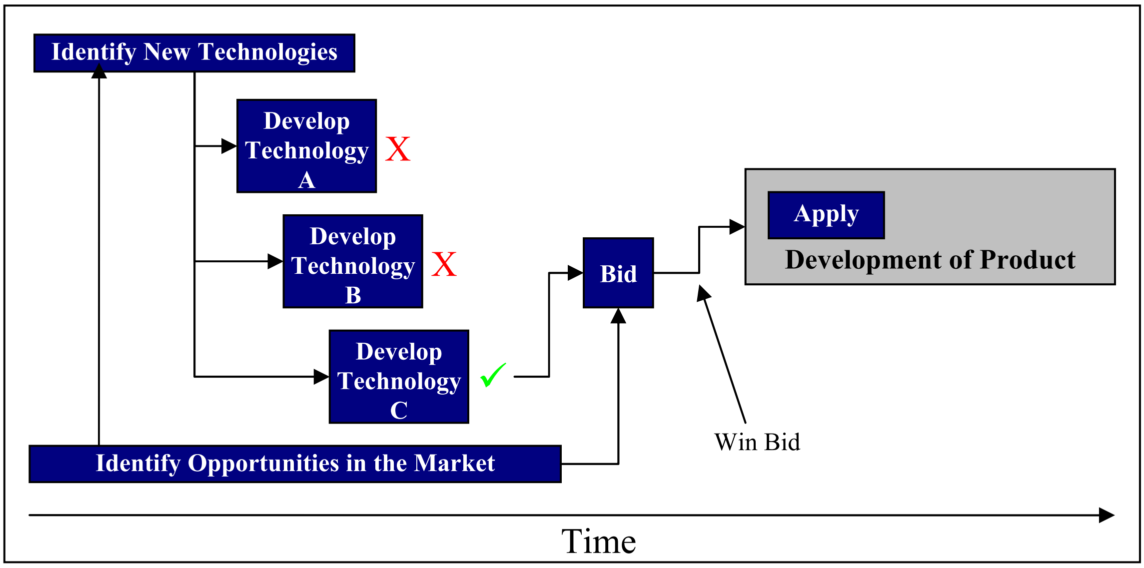


Figure 4: Ideal method of developing new technology

What would be the ideal scenario is if all technological development could occur before a bid was made (Figure 4). The coatings for the F16, for example, could have been tried and tested before submitting a bid, at which point the costs of research and development could have been factored into the total report costs.

Due to the size of the company, without involvement from the parent group, it cannot afford the large upfront investments required for all research and development to be conducted outside of a project budget. But, even if just some of the new technology was developed or even acquired by the aviation subsidiary company before the bid procedure it would allow bids to be submitted that were more accurate and carried less risk.

These same conclusions were independently drawn by the Avila consultancy that more should be done to identify new technologies before they are required for a specific report. This would mean that the aviation subsidiary company would have a more complete understanding of the complexity of a new technology before it was requested by a customer in a report using such a technology.

Depending on the maturity of a technology and the applicability of a technology four strategies were formed by the aviation subsidiary company with Avila Consultancy, to deal with new technologies, they are as follows:

1. **Generic/Established** technologies that would be **bought in**
2. **Highly Specific/Established** technologies that would be developed **in-house**
3. **Generic/Fundamentally New** technologies that would require **sponsoring selected institutions**
4. **Highly Specific/Fundamentally New** technologies that would require the **secondment** of an the aviation subsidiary company staff member to a research institution

The aviation subsidiary company is currently not fully committed to these strategies, although it should be noted that two senior engineers have been tasked to address new technologies. One engineer is responsible for finding funding and partnerships for the development of new technologies. The other is tasked with finding new technologies and assessing their capabilities and relevance to the aviation subsidiary company's operations. The level of interaction between the two is however minimal.

4.3. Procedure For Selecting New Technology

Utilising a questionnaire the current perceptions of the selection of new technology at the aviation subsidiary company was evaluated. The overall conclusion is that the current procedure for selecting new technology was unsatisfactory. The reason for this result is because an actual documented procedure for selecting new technologies does not currently exist at the aviation subsidiary company. The selection of new technologies has been left to the discretion of the experts within the company. Although it is felt that these are the correct people to be involved in the decision-making process, the absence of any formal documentation or procedure means that the reasons for certain decisions are not recorded and the method of approaching each selection decision has been different each time. In addition, the lack of any tools to assist the selection decision has made the task of assessing the often subjective and uncertain information surrounding new technology alternatives much more difficult.

5. Development Of The Proposed Methodology

5.1. Identification Of New Technology

The initial phase of the selection procedure must be to identify the possible new technologies that meet the company's requirements. It is recommended that a research review of innovative technologies is undertaken by a research officer. One approach for undertaking such a review would be to conduct an in-depth literature review. It is expected that the company's experts would also have relevant experience and knowledge of the most recent technologies within their field. The company may also be able to draw from strong customer relations in order to capture knowledge from the customer's expertise. For example, in the aviation subsidiary company's situation, they have a very good working relationship with Lockheed Martin, which enables them to share information on developing technologies. In addition, thorough market analysis should elicit any developments being considered by competitors. It is hoped that with these measures most of the relevant new technologies will be identified to be included in the selection decision. It is acknowledged that the company may use other measures in order to identify new technologies. For example, the company could build closer relationships with universities and research centres during the development of 'blue-sky' technologies.

5.2. Previous Methods For Technology Selection

5.2.1. Technology Selection Algorithm

Chan *et al.* (2000) presented a technology selection algorithm to quantify both the tangible and intangible benefits of certain technologies in a fuzzy environment. Specifically, an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluation. A systematic approach was developed to overcome the difficulties associated with technology selection and justification. A schematic diagram detailing the stages of technology selection and justification is shown in Figure 5.

Stage 1. Form a committee of decision-makers who come from different managerial levels of the company. Identify various available *m* technologies (A1; A2; . . . ; A_m) under each of the *k* criteria (C1; C2; . . . ; C_k).

Stage 2. Choose proper linguistic scale (say 'high', 'medium' and 'low') and ask decision-makers to give their judgement by either directly assigning weight in triangle fuzzy numbers or indirectly using pair wise comparisons.

Stage 3. Explode criteria hierarchically and classify into subjective and objective criteria (Figure 6).

Stage 4. Subjective criteria, such as flexibility and quality, are characterized by linguistic assessments. On the other hand, objective criterion, i.e. economic, is evaluated in monetary terms. For instance, investment cost, operating expenses, etc., which are calculated by fuzzy cash flow model. The equation is:

$$X_{mj}=(G_{mj}-C_{mj})-(G_{mj}-C_{mj}-D_{mj})T_m-K_m+L_{mj}+V_{mj} \quad (1)$$

Where X_{mj} is the net total cash flow of the technology *m* at the end of year *j*, G_{mj} the turnover of the technology *m* at the end of year *j*, C_{mj} the operating expenses of the technology *m* at the end of year *j*, D_{mj} the depreciation amount of technology *m* in year *j*, T_{mj} the tax rate of the technology *m*, K_{mj} the investment cost of the technology *m*, L_{mj} the salvage value received in year *j*, and V_{mj} is the incremental tax credit of the technology *m* in year *j*.

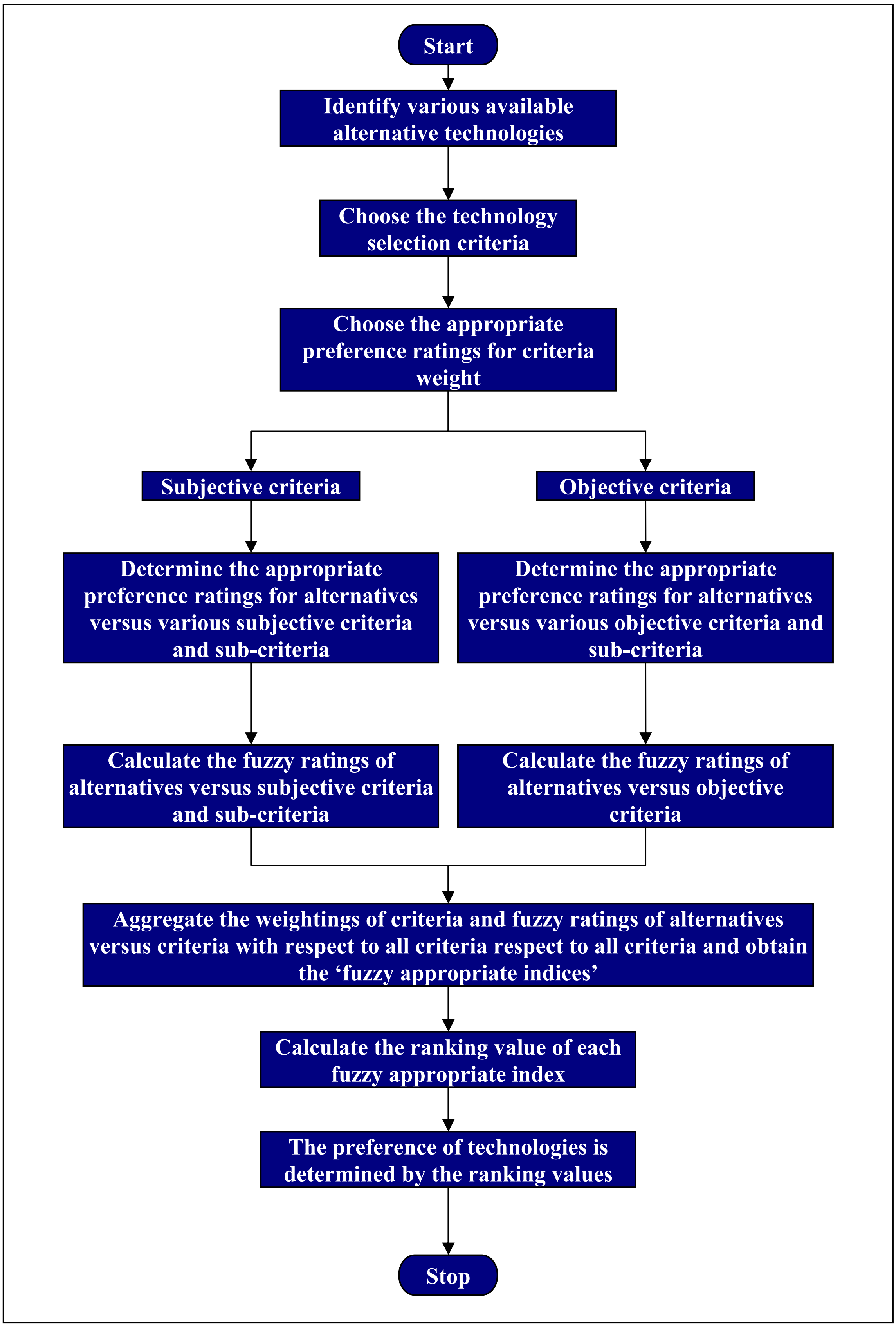


Figure 5: The schematic diagram of technology selection and justification (Chan *et al*. 2000)

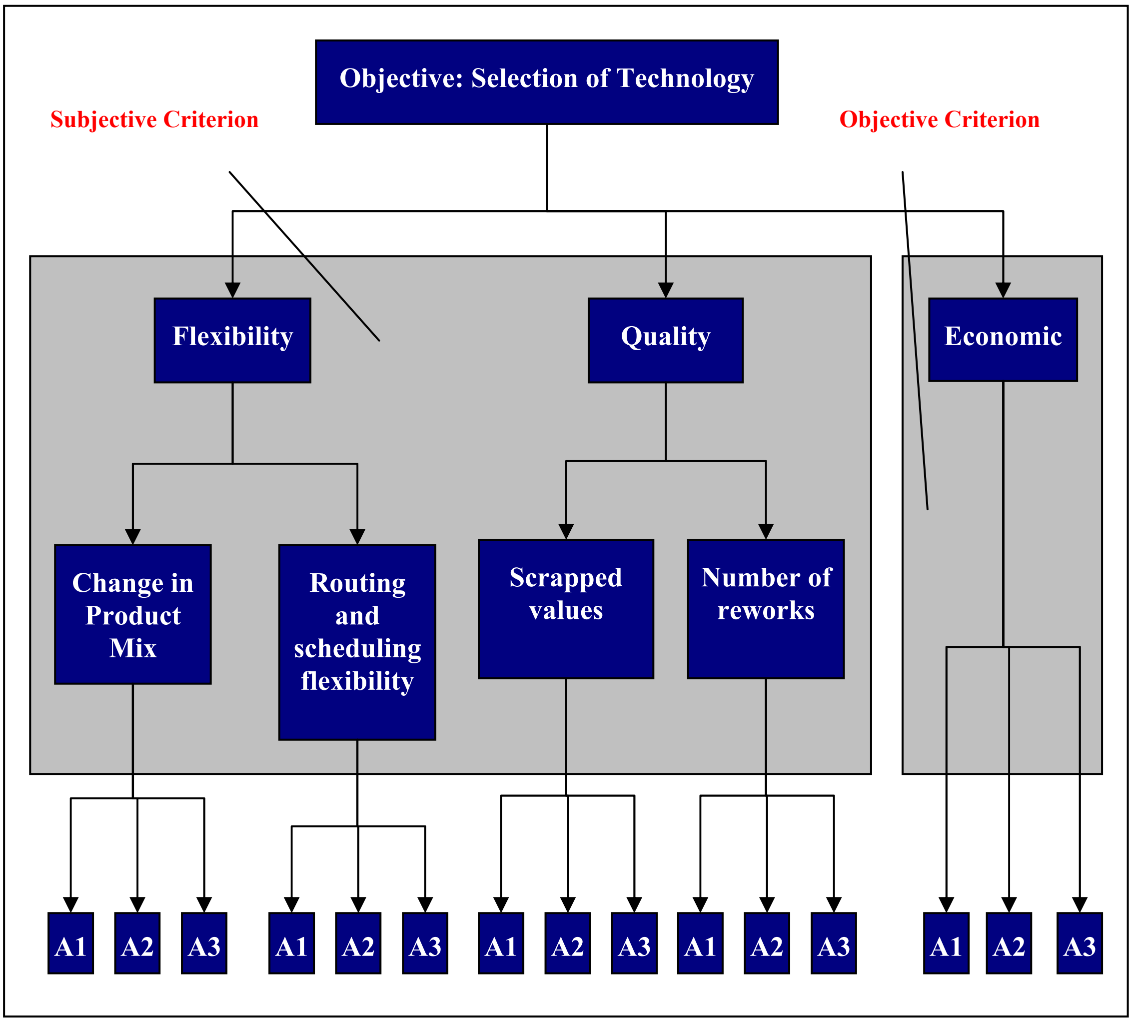


Figure 6: Hierarchical structure for hypothetical example
(Chan *et al*. 2000)

After the fuzzy cash flow is calculated, the NPV of *m* technology can be determined by:

$$NPV_m = \sum_{n=0}^{j} \frac{X_{mj}}{(1+i^n)} \quad (2)$$

Where NPV_m is the net present value of technology *m*, *i* is the discount rate, and *j* is the life of a report.

All the variables stated in Equations. (1) and (2) are specified as triangular fuzzy numbers which represent 'the most likely possible value', 'the most pessimistic value' and 'the most optimistic value'. The calculated fuzzy NPV is then used to provide financial data for further analysis.

Stage 5. Convert the linguistic variables into triangle fuzzy numbers through a designed rating scale as seen in Figure 7.

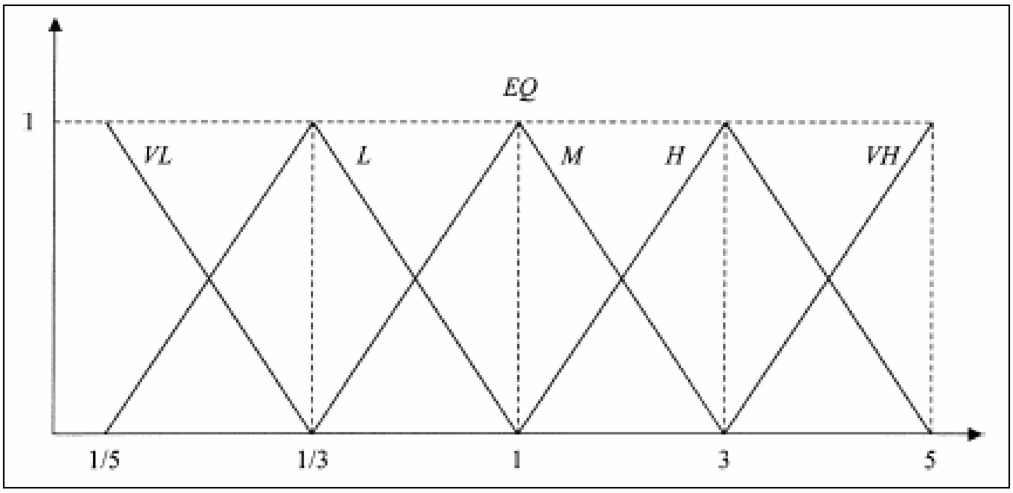


Figure 7: Example of a possible membership function for linguistic values (Chan *et al*. 2000)

Stage 6. Construct a fuzzy reciprocal matrix of various criteria as well as sub-criteria. The geometric row means of each fuzzy reciprocal matrix is calculated. Then the normalization of geometric row means is obtained in order to indicate the importance in terms of weightings of each criterion as well as the sub-criteria and appropriateness of technologies.

Let S_{mk} be the weight of technology A_m versus criterion C_k, W_k be the weight of criterion C_k and a_{ij} be the element of fuzzy reciprocal matrix.

Geometric row mean is given by:

$$r_i = (a_{i1} \times a_{i2} \times a_{i3} \ldots \times a_{ik})^{1/k} \quad (3)$$

Normalized geometric row mean is given by:

$$W_k = \frac{r_i}{(r_1 + r_2 + r_3 + \ldots + r_k)} \quad (4)$$

Stage 7. Aggregate the hierarchy by the corresponding products, S_{mk} and W_m over all the criteria. The fuzzy appropriate index (FAI_m) of the *m*th technology can be obtained by standard arithmetic method.

$$FAI_m = (\frac{1}{k}) \times ((S_{m1} \times W_1) + (S_{m2} \times W_2) + \ldots + (S_{mk} \times W_k)) \quad (5)$$

Stage 8. For ease of implementation and powerfulness in problem solving, Kim and Park's (1990) method is used to rank the fuzzy appropriate index. It represented the final preference order of technologies. Figure 8 illustrates an example of the left and right score produced by Kim and Park's method.

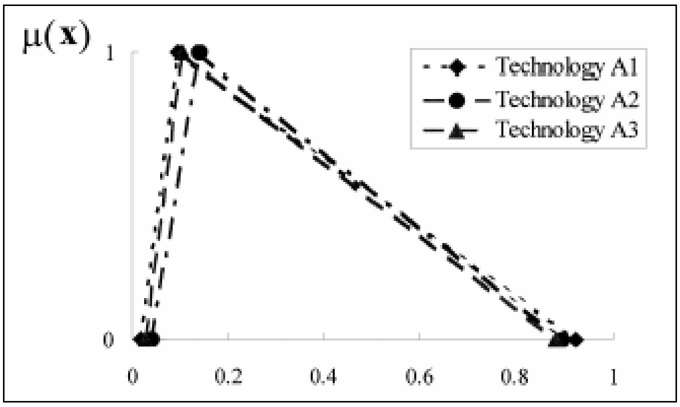


Figure 8: Example of the left score and right score ranking (Kim and Park 1990)

5.2.2. NASA's Consensus Ranking Organisational Support System

CROSS (Consensus Ranking Organisational Support System) presented by Tavana (2003) is a multi-criteria group decision-making model that has been implemented successfully at Kennedy Space Centre in the USA. Its aim is to capture the decision-makers' beliefs through sequential, rational and analytical processes. CROSS uses the Analytical Hierarchy Process (AHP), subjective probabilities, the entropy concept and the Maximise-Agreement Heuristic (MAH) to enhance the decision-makers' intuition in evaluating sets of advanced technology projects. CROSS guides the decision-makers through a systematic evaluation of the projects and uses the decision-makers' judgements to construct an overall composite score called the project success factor. CROSS has three phases: an interaction phase, an integration phase, and an interpretation phase (Figure 9). Each phase consists of several steps. The evaluation process begins with an initial interaction of the decision-makers. After a preliminary review of the project proposals, the decision-makers identify the stakeholder departments that should participate in the evaluation (Atep 1). Stakeholder departments are responsible for the implementation of the selected projects. The decision-makers use AHP in Step 2 to weight the stakeholder departments for their importance. Next, the committee gives the stakeholder members detailed and comprehensive information about the proposed projects. In Step 3, the stakeholders meet separately with members of their departments to decide what criteria the committee should consider in evaluating the projects. They also use AHP to weight these criteria for their importance. Then, the members of each stakeholder department meet in several brainstorming sessions to assign a probability of occurrence to each criterion for each project based on their expertise and past experience (Step 4). After gathering this information, the members of each department use a series of automated tools in Step 5 to calibrate the results. They begin by adjusting the importance weights of the criteria identified in Step 3 with the probabilities of occurrence from Step 4. In Step 6, the decision-makers use an Excel program of the model to calculate their individual scores for each project. They also use MAH in Step 6 to come to a consensus in ranking all projects. During the interpretation Steps 7 and 8, decision-makers consider the output from CROSS and make a final recommendation for management approval.

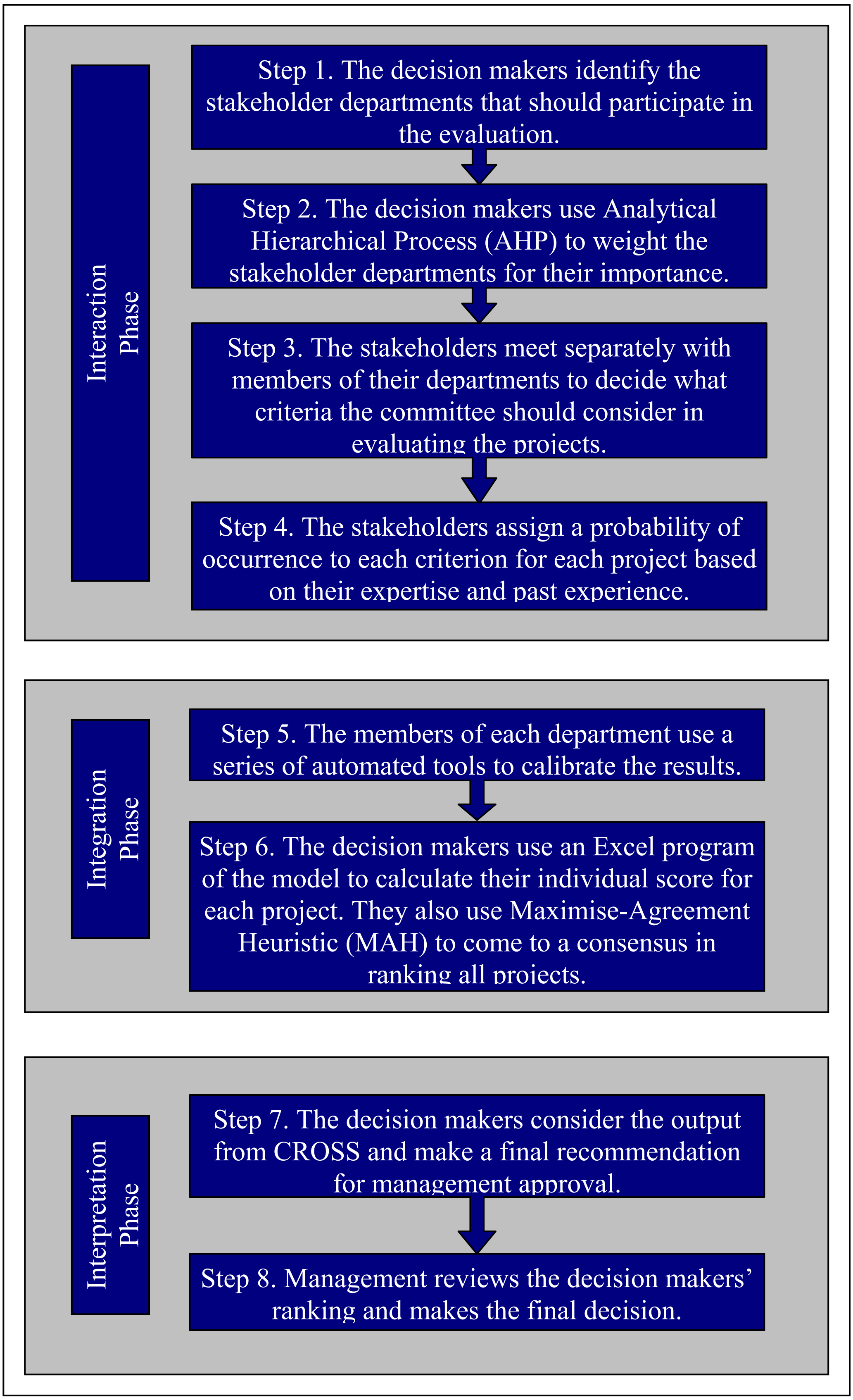


Figure 9: The Three Phases of CROSS (Tavana 2003)

5.3. Recommended Methodology For Selection Of New Technology

The proposed methodology is a consolidation of the best methods highlighted in the previous section that have then been adapted to the specific requirements of the aviation subsidiary company. Figure 10 summarises the steps required to complete the selection process and highlights the areas that are completed by the computer model with a lighter shaded box for steps 7 - 11.

Initially the need for a new technology needs to be identified. This can be done by either the existing product development procedure, which is currently being reviewed to allow the development of products before they are actually required by the customer, or anyone within the company that insures that there is no limit to the type of ideas that can be put forward. Once this need has been proposed, senior management discuss the situation and decide on whether the need is great enough to require investment in the new technology. If it is decided that the area of need can be justified for investment in a new technology, the selection of the technology can begin.

Similar to the NASA procedure stated previously, though on a smaller scale, a report manager should be assigned and the interested parties identified to ensure that everyone's ideas are considered. As described in section 5.1, a search can then begin to discover the technologies that can suitably address the need or meet the specification. Once the relevant technologies have been identified and as much information about the alternatives has been gathered, it is possible for the decision-makers, who were identified as the interested parties earlier, can make their judgements on each of the technologies. At this stage, the computer model that has been developed can be utilised. It is based upon the methodology presented by Chan *et al.* (2000). It is used to capture the linguistic descriptions of the relative importance of the subjective criteria and a range of possible values for the objective criteria. This means that accurate information is not required on each technology, just a comparative assessment of each technology and a rough idea of the expected values.

Section 6 describes in detail the use of the model and Section 5.2.1 explains the calculations that the model handles. A few key points should, however, be highlighted. The model produces a final ranking for each of the technology alternatives in order of suitability, having compared each technology against all of the different criteria. It also presents on the same worksheet the Net Present Value (NPV) for each, as although they have already been included in the comparison, the NPV value is highly significant to the financiers of the technology investment. The model also captures any assumptions that have been made during the generation of the results and provides a tool for recording all of the decisions that have been made. This functionality allows the decisions to be reviewed in the future, either to compare against the actual findings once a technology has been implemented, or to try and identify where inaccurate judgements or decisions were made so that mistakes are not repeated in the future. The methodology then recommends that a thorough risk analysis is undertaken on the top ranking technology. By conducting the risk analysis at this stage, it can be purely concentrated on the top ranking technology, thus saving the time and resources that would be required to assess all of the risks for all of the technology alternatives.

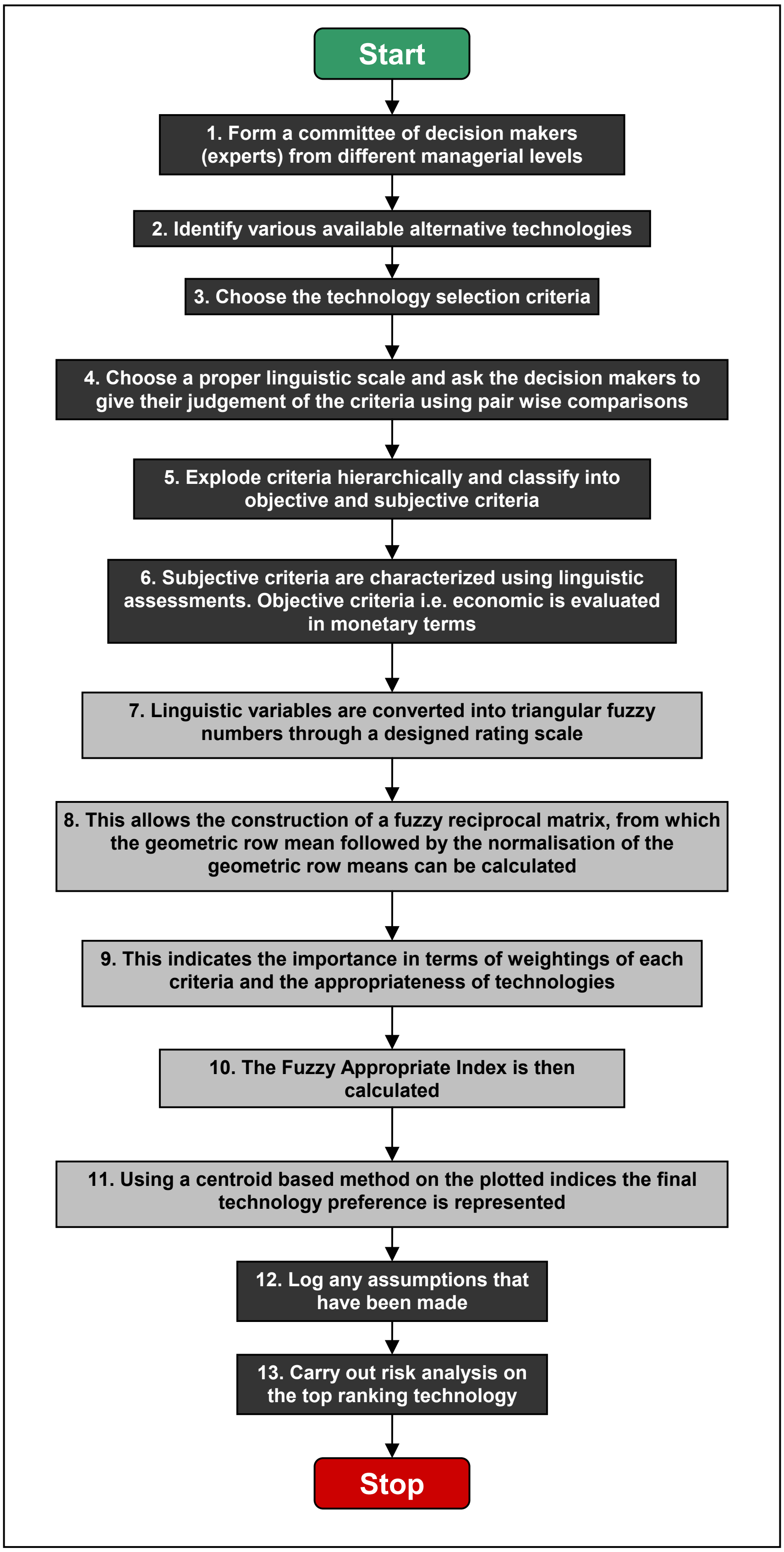


Figure 10: Proposed methodology

5.4. Risk

This research has not been able to address risk within the prototype model. Despite this, it is considered necessary to document a method that could be utilised at a later date to measure the risks involved. Initially, the model was going to contain a certain measure of risk by quantifying the size of the range of fuzzy NPV values for a certain technology. This method was not used as no previous work had been undertaken to prove its suitability. A method was discovered in the automotive industry that measured risk after assessing new technologies which could be added to the proposed methodology at a later date.

There is always an element of risk in the selection of new technologies. Having modelled several alternative technologies, the technology choices need to undergo a further evaluation process based on the intended objective - with the final result being a prospect and risk statement.

The individual technology elements are based on a host of individual criteria, which are structured in hierarchical evaluation trees. On the lowest level, the individual criteria can be evaluated by using any probability function. Transformation functions standardise the probability distributions of the criteria strengths to a uniform evaluation scale. Then they are aggregated into a total assessment statement at the level of the criteria trees by using a Monte Carlo simulation, finally, based on the final evaluation targets this method results in a prospect and risk statement about the technology in question.

From the point of view of results-orientated product development, the essential evaluation criteria for technologies must be taken from the requirements for a product evaluation, so that they may be distinguished by:

- Cost
- Quality
- Flexibility

In addition to the listed criteria, it will be necessary to introduce the degree of maturation of a technology as a measure for the development uncertainties or risks during the product development phase, in order to arrive at an assessment regarding the realisation and usability of technology.

Cost plays a decisive role in realising product functions and in this context, also for technologies. In the early phases of development and design, the largest percentage of cost is assigned, while only a minor percentage of costs actually arise there. This shows that the decision to go with one technology choice involves considerable determination of cost for the subsequent functional areas.

The quality of technologies is an essential prerequisite for fulfilling product functions and as such, it must be guaranteed. Sub-criteria for quality are the fulfilment of functions, ease of diagnostics, robustness and image achieved. Fulfilment of function is further divided into the sub-criteria: fulfilment of function from a customer’s point of view and from the point of view of the company, since these two parties may have different requirements for each technology alternative to be evaluated.

Flexibility is the ability to adapt to changes and to provide the adoption processes required in a timely and focussed manner. Due to increased complexity of technologies, this increasingly ties up development resources, raises the development risk and considerably length of time to market which is becoming increasingly essential due to shrinking life cycles. The degree of maturation of a technology expresses the potential risk for reaching production readiness of a technology alternative, and whether a technology will continue to represent an appropriate solution in the future. Having considered all of these facets of new technology risk the decision-makers' should be able to proceed with increased confidence towards a definite selection decision.

6. Model Prototype And Validation

6.1. Model Structure

This section describes the structure of the computer model that has been developed and how each worksheet in the model relates to the proposed methodology illustrated in figure 10. The model has been produced in Microsoft Excel to provide ease of use and is designed to have a similar appearance to the company's business model, in order to provide familiarity. The template of the model provides three sample criteria and the space for three technologies to be compared. These are easily replaced as necessary and with a basic understanding of Microsoft Excel additional cells can be added to the tables to include an increased set of criteria or more technology alternatives.

As the model has been developed in Excel the structure of the model is split by different worksheets found at the bottom of the spreadsheet program. They are as follows:

- Title Page
- Instructions
- Selection Summary
- Assumptions
- Technologies
- Criteria
- Opinions
- Economic Data
- Definitions of Economic Data
- Fuzzy Calculations
- Fuzzy Weightings Summary
- Net Total Cash Flow
- Net Present Value

The model opens up with a title page (Figure 11) in which the user can enter information identifying the particulars of the selection decision, along with any comments that are required, perhaps the names of the decision-makers involved in this selection. The title, once entered, is reproduced automatically across the top of all of the worksheets.

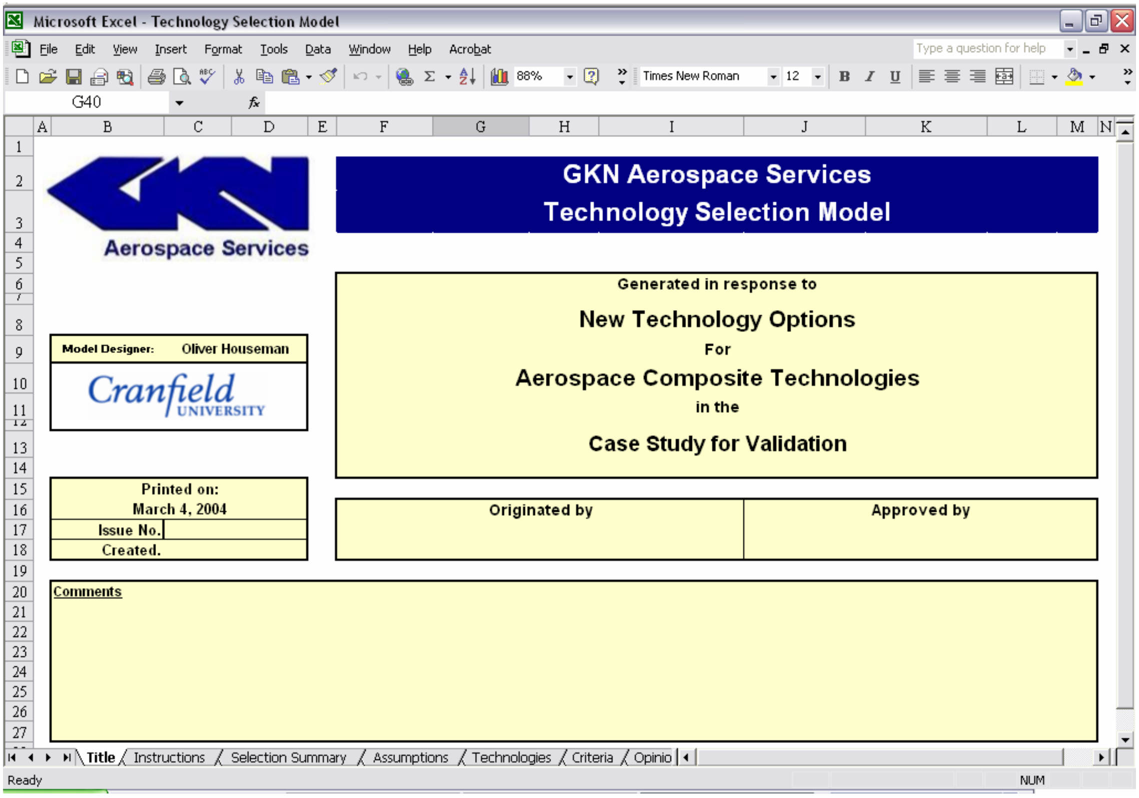


Figure 11: Sample of the title page

Following the title page is the instruction page containing the specific steps involved in completing the model (see section 6.2). The next worksheet is called the 'Selection Summary' it is where the results are shown from the running of the model. After the 'Selection Summary' page is the worksheet to record the assumptions that have been made during the completion of the model in line with step 12 of the methodology. These assumptions would be those required for the particular judgements that have been made by the decision-makers.

The next worksheet gives the list of the technologies to be compared with a short description of each. This would be populated from the results of step 2 of the methodology. The 'Criteria' worksheet following the list of technologies is where the list of criteria by which the technologies are to be compared is listed and as instructed by step 5 of the methodology they are exploded hierarchically. The first worksheet where the judgements of the decision-makers are recorded is the 'Opinions' worksheet (Figure 12).

At the top of the 'Opinions' worksheet is an example of a triangular fuzzy scale for defining the fuzzy linguistic terms used for describing the relative importance of the criteria and technologies, corresponding to step 4 of the methodology. This may be adjusted to suit the decision-makers' requirements but provides a standard method with which to begin. Below this are the tables to capture the judgements of the decision-makers when comparing the criteria by pair wise comparison also required by step 4. Finally, below these tables are the tables to capture the characteristics of the technologies as stipulated by step 6 of the methodology.

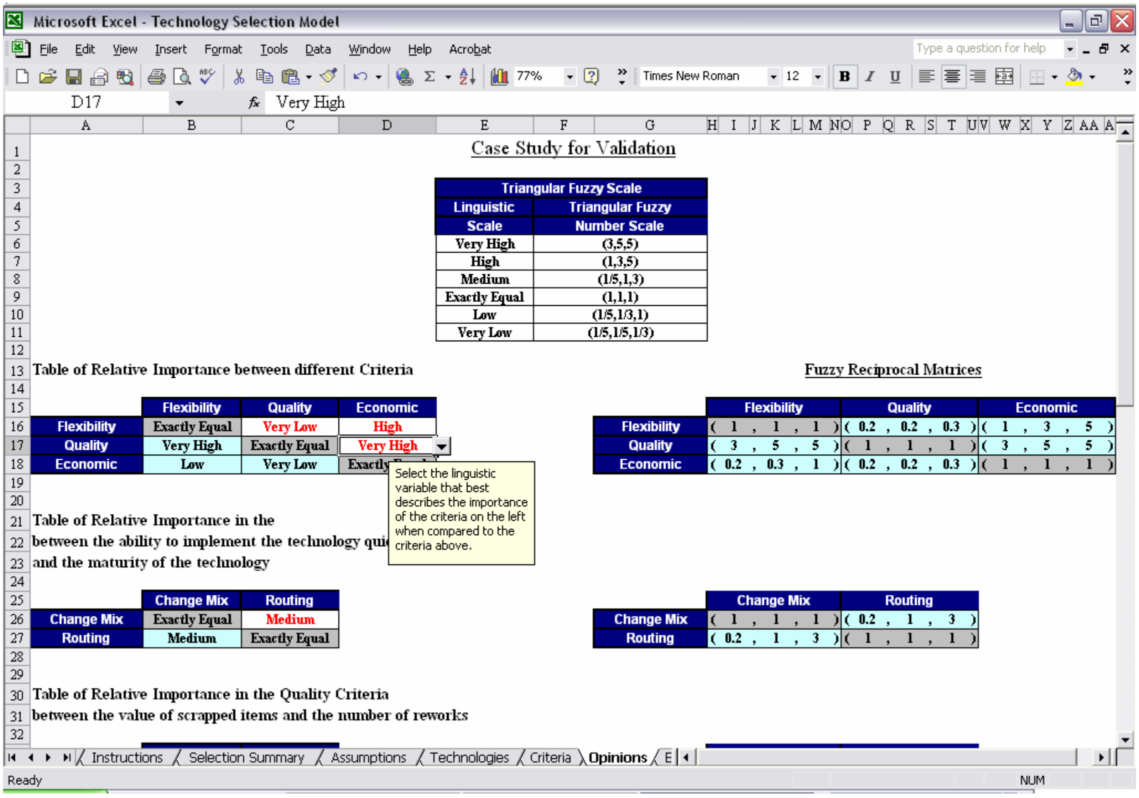
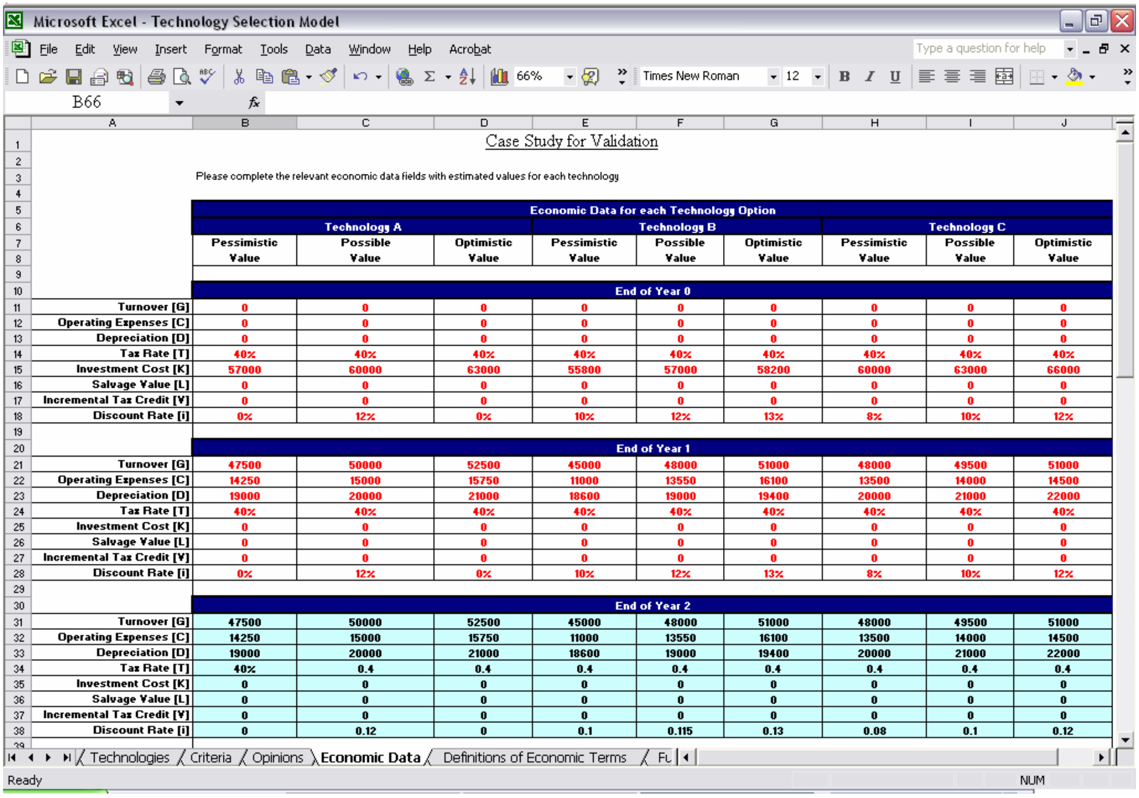


Figure 12: Sample of the 'Criteria' worksheet

In Figure 12 it can also be seen that the fuzzy reciprocal matrices required by step 8 of the methodology are calculated to the right of the relative importance assessments. This is done automatically once a value is selected from the drop down menu in the relative importance tables. To reduce the time required to complete the model, only the top right hand side of each table needs to be completed as the model will automatically complete the other side of the table with the opposite linguistic term.

The user of the model can then assess the fuzzy calculations and resulting fuzzy weightings of step 8 and 9 in the worksheets ‘Fuzzy Calculations’ and ‘Fuzzy Weightings Summary’ respectively, if necessary. This will not usually be required and the next worksheet to be completed is the ‘Economic Data’ table (Figure 13).

The economic data is assessed by inputting an optimistic, pessimistic, and most possible figure for each of the values required. Once again, to reduce the time to complete the model, some data such as tax rate only needs to be inputted once for each technology, as these can be considered constant, although individual values could be used if necessary. This data is then automatically calculated as required by step 6 on the next two worksheets to produce the fuzzy Net Present Value (NPV) for each technology.



Case Study for Validation

Please complete the relevant economic data fields with estimated values for each technology

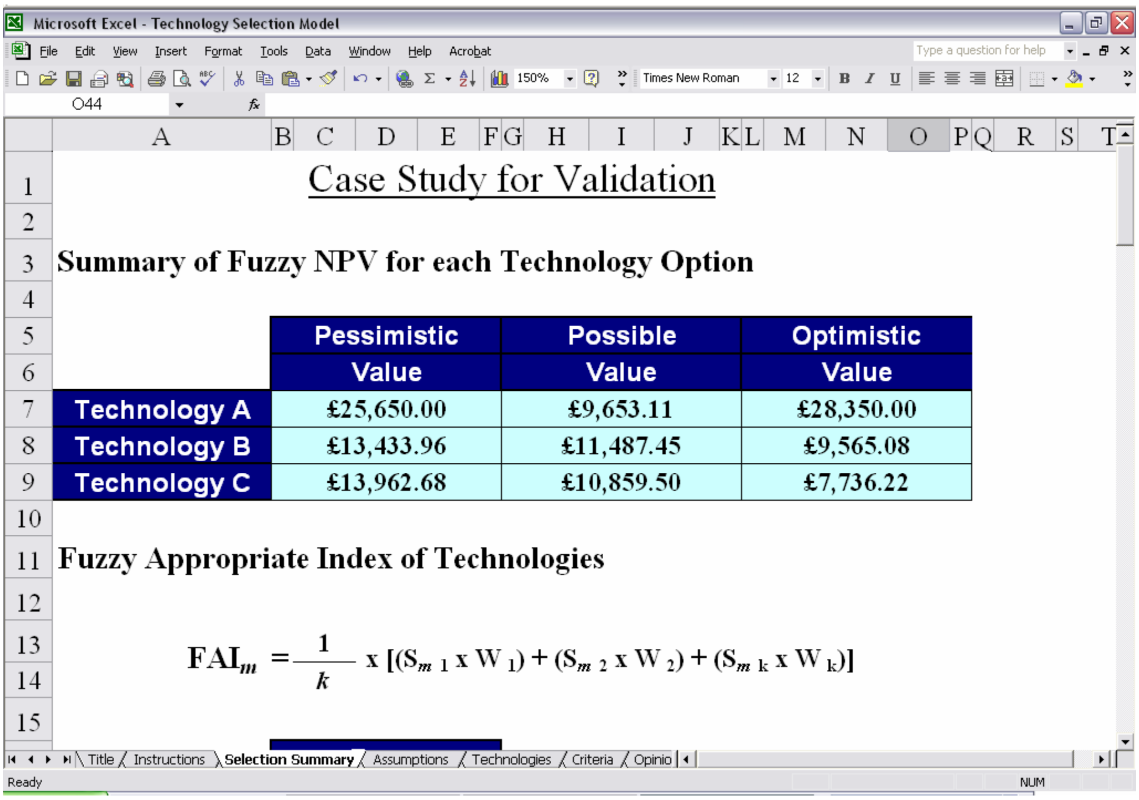
	Technology A			Technology B			Technology C		
	Pessimistic Value	Possible Value	Optimistic Value	Pessimistic Value	Possible Value	Optimistic Value	Pessimistic Value	Possible Value	Optimistic Value
End of Year 0									
Turnover [G]	0	0	0	0	0	0	0	0	0
Operating Expenses [C]	0	0	0	0	0	0	0	0	0
Depreciation [D]	0	0	0	0	0	0	0	0	0
Tax Rate [T]	40%	40%	40%	40%	40%	40%	40%	40%	40%
Investment Cost [K]	57000	60000	63000	55800	57000	58200	60000	63000	66000
Salvage Value [L]	0	0	0	0	0	0	0	0	0
Incremental Tax Credit [V]	0	0	0	0	0	0	0	0	0
Discount Rate [i]	0%	12%	0%	10%	12%	13%	8%	10%	12%
End of Year 1									
Turnover [G]	47500	50000	52500	45000	48000	51000	48000	49500	51000
Operating Expenses [C]	14250	15000	15750	11000	13550	16100	13500	14000	14500
Depreciation [D]	19000	20000	21000	18600	19000	19400	20000	21000	22000
Tax Rate [T]	40%	40%	40%	40%	40%	40%	40%	40%	40%
Investment Cost [K]	0	0	0	0	0	0	0	0	0
Salvage Value [L]	0	0	0	0	0	0	0	0	0
Incremental Tax Credit [V]	0	0	0	0	0	0	0	0	0
Discount Rate [i]	0%	12%	0%	10%	12%	13%	8%	10%	12%
End of Year 2									
Turnover [G]	47500	50000	52500	45000	48000	51000	48000	49500	51000
Operating Expenses [C]	14250	15000	15750	11000	13550	16100	13500	14000	14500
Depreciation [D]	19000	20000	21000	18600	19000	19400	20000	21000	22000
Tax Rate [T]	40%	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Investment Cost [K]	0	0	0	0	0	0	0	0	0
Salvage Value [L]	0	0	0	0	0	0	0	0	0
Incremental Tax Credit [V]	0	0	0	0	0	0	0	0	0
Discount Rate [i]	0	0.12	0	0.1	0.115	0.13	0.08	0.1	0.12

Figure 13: Sample of the economic data table

The NPV's are used to calculate a fuzzy weighting for the economic criterion and because the economic assessment is usually one of the more important pieces of information, the specific values are specifically displayed on the 'Selection Summary' worksheet as shown in figure 14.

The inputs to the model are now complete, the model now calculates automatically the Fuzzy Appropriate Index, step 10 of the methodology, and then represents the results further down the 'Selection Summary' worksheet to the user and decision-makers having completed step 11 of plotting the indices and using a centroid based method to rank the possible technologies in order of preference (Figures 15 and 16).

This section has demonstrated the model's ease of completion. This achieves the original aim of the design. In theory, once the title page has been completed there are only two sheets that need to be filled in before a result can be reviewed. This enables completion of a number of selection decisions very quickly and for the decision-makers to see whether or not changing one decision can affect the result.



	Pessimistic Value	Possible Value	Optimistic Value
Technology A	£25,650.00	£9,653.11	£28,350.00
Technology B	£13,433.96	£11,487.45	£9,565.08
Technology C	£13,962.68	£10,859.50	£7,736.22

Figure 14: Sample of the top of the selection summary

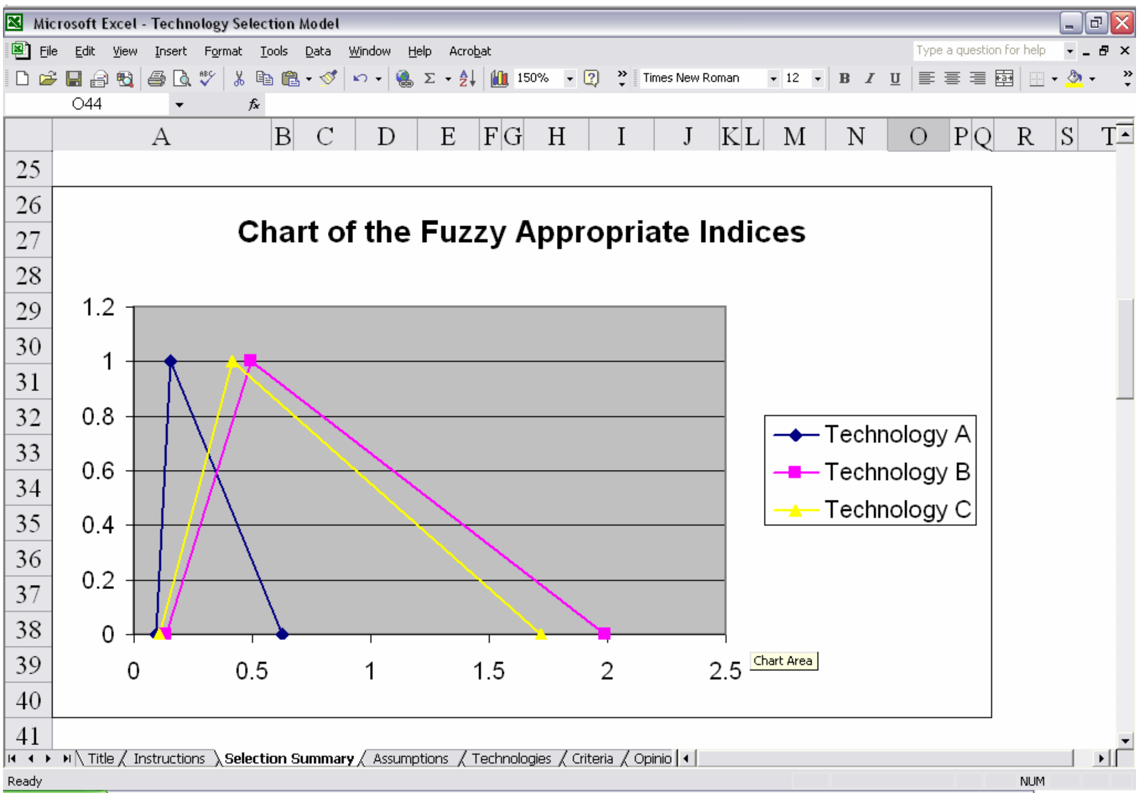


Figure 15: Chart of the fuzzy appropriate indices

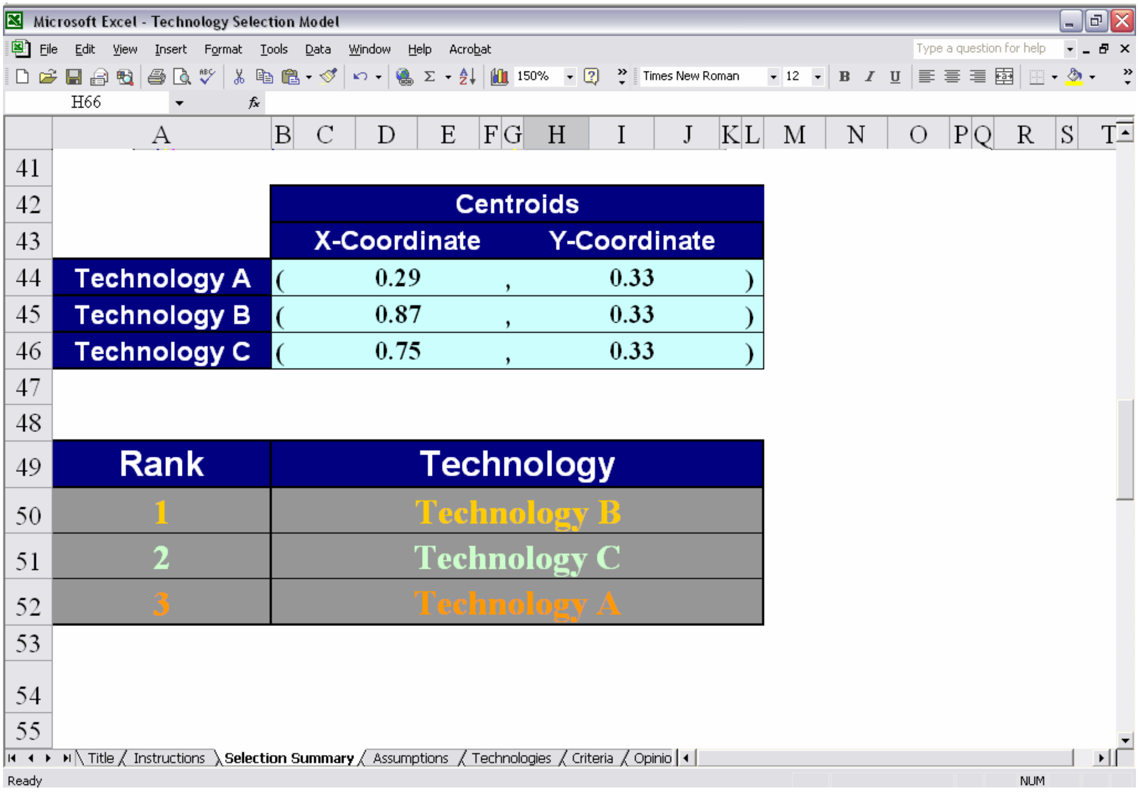


Figure 16: Sample of the selection summary displaying the final rankings

6.2. Model Usage

This section provides a step by step guide to how the software model is to be used when implementing the proposed methodology.

Once the group of decision-makers have identified the technology alternatives and collected enough information about each option to be able to make rough judgements on certain comparisons, the software model can then be used to capture those judgements and compare the technologies in order to finally present them in a ranking order. The judgements are about the relative importance of each criterion that the technologies are being assessed against and the range of possible values for economic data.

The steps to complete the model are:

1. Initially fill out the title page to record the technology selection being evaluated.
2. Then complete the table with the name of the technology alternatives and a short description of each.
3. Proceed to the 'Criteria' tab and confirm that the default criteria to be compared are relevant to the technologies being evaluated, if not, change to suit.
4. Complete the 'Opinions' worksheet by assigning linguistic terms to describe the relative importance and preference of the criteria. (Note: Only the top right-hand side of each table needs to be completed as the model will automatically complete the other side of the table).
5. The model then completes the fuzzy calculations and presents the 'Fuzzy Weightings' of each criterion for appraisal if necessary.

6. The 'Economic Data' then needs to be completed capturing the opinions of the decision-makers on economic values. (Note: Some data such as tax rate only needs to be inputted once for each technology as these can be considered constant, but individual values could be used if necessary.)
7. That completes the input required by the user. The model then completes the economic calculations and produces the NPV.
8. The last input is to record any assumptions that would effect the decisions made.
9. The final step is to look at the 'Selection Summary' that illustrates the final ranking positions of the technologies.

Once these steps have been completed it is important that the group of decision-makers meet again to discuss the results and perhaps re-run the model with altered figures to represent different scenarios. If the same technology is consistently calculated as the preferred technology a thorough risk analysis should then be carried out on that particular technology in line with step 13 of the methodology.

To summarise, the inputs required for the model are;

- Information identifying the particulars of the selection decision, together with any comments that are required about the decision.
- The technologies that are to be evaluated.
- The criteria by which the technologies are to be compared.
- The opinions of the decision-makers in linguistic terms about the relative importance of each criteria against one another.
- The opinions of the decision-makers in linguistic terms about the relative importance/preference of each technology for each criteria.
- The opinions of the decision-makers of the pessimistic, optimistic and most likely values for certain economic data relating to the technologies.
- The assumptions that have been made in making these decisions.

Once the model has been run the outputs from the model are;

- The Net Present Values for each technology over a defined period.
- The Fuzzy Appropriate Indices for each technology.
- A ranking order of preference for the technologies.

6.3. Case Study

A case study was undertaken to validate the use of the proposed methodology within the company. The case study focused on the use of the model in evaluating three different manufacturing techniques for the production of fighter jet canopies. The three technologies were:

- *Next Generation Transparency Technology*
  This consists of utilising injection moulding techniques.
- *Forming Technology*
  This is the current method used and forms the canopy using heat and pressure.
- *Blow Moulding Technology*
  This is an unknown technique to the aviation subsidiary company but uses a vacuum to suck the canopy into shape once it has been heated.

Following the instructions found with the model, the judgements on the different technologies were captured and a result produced (Figure 17). The following points were made about the model which could then be applied to improve the overall value of the model.

Initially, the template of the model provided the aviation subsidiary company with three criteria to evaluate the proposed technologies. The criteria were ‘flexibility’, ‘quality’ and ‘economic’. Findings from running the case study indicated that the criteria should be changed to suit the aviation subsidiary company’s requirements. The new criteria became ‘time’, ‘performance’ and ‘cost’. The change to the ‘flexibility’ criteria to ‘time’ obviously required revision to the sub-criteria. The sub-criteria for ‘time’ became ‘maturity’ and ‘availability’.

A further outcome of the case study was the request for more definitions of the terms used in the model. This required the introduction of a Table similar to the one completed to record the different technologies where a description of each criteria could be recorded. It was also felt that the definitions for the economic terms were required to assist completion of the model. These financial terms are standard and should be able to be further defined by the aviation subsidiary company’s accountants.

Finally, a number of cosmetic issues were recommended to improve the presentation and use of the model in the company. These included colour coding the values that required user input and locking the cells that contained values that should not be adjusted.

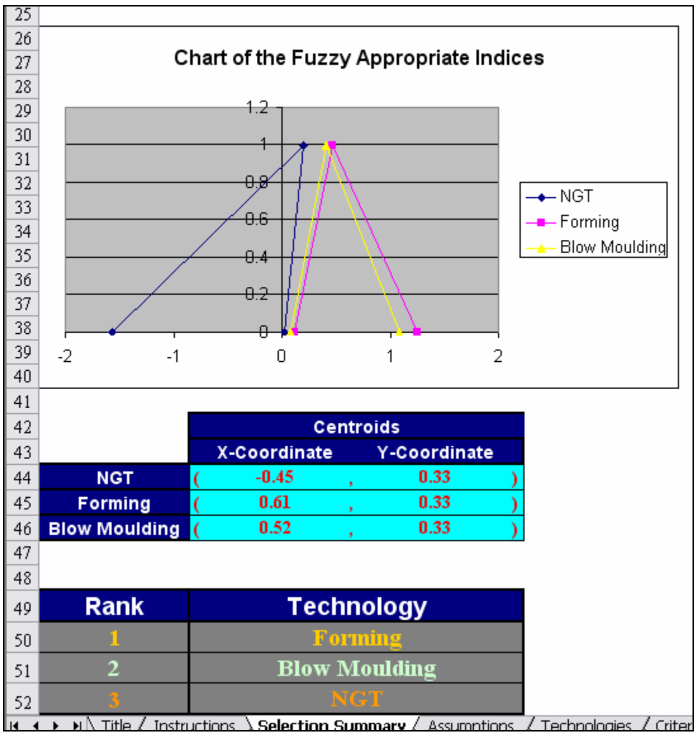


Figure 17: Results from the case study

7. Discussion

7.1. The Proposed Methodology

The presented model provides an easy-to-use tool that calculates all of the complex fuzzy set theory. It also addresses the requirements for explicitness, consistency, simplicity, flexibility, decision-maker participation, decision-process quality and decision quality.

The methodology encourages the interaction of key personnel which ensures that the decision-making process contains relevant experts' points of view. The model can either be completed on an individual basis and the results then compared, or by a committee who input the data collectively.

The model's platform in Microsoft Excel allows users to graphically alter their judgements and see on the screen how these change the relative weightings. The use of Excel also ensures scalability that allows the inclusion of further selection theories as they are published in the literature.

7.2. Limitations Of The Methodology

The proposed methodology would be enhanced by the inclusion of a module that conducts sensitivity analysis on the model's output. This would allow the calculation of the minimum change required in the weight of a criterion to cause rank reversal among alternatives. The methodology also assumes that there is more than one technology available for selection and that there are sufficient expert opinions to evaluate their criteria.

The methodology is not intended to replace human judgement in technology selection at the aviation subsidiary company. In fact, human judgement is its basic input. The methodology helps decision-makers to think systematically about complex technology selection problems and improves the quality of their decisions. It is almost impossible to obtain objective data on the characteristics of most advanced technology projects because of inherent uncertainties. However, experienced decision-makers can often make fairly accurate estimates of values for these characteristics. The methodology combines these subjective values numerically to provide an overall ranking for each technology.

7.3. Contribution To Knowledge

This report has provided a formal methodology for the selection of new technologies within the Aviation industry. It has provided a procedure that can be followed to ensure the correct new technologies are selected for investment. A computer-based model has been developed that simplifies the complex calculations surrounding fuzzy logic. Fuzzy logic has been utilised to deal with the uncertainties surrounding new technologies and give decision-makers the flexibility of using rough estimates and linguistic terms to describe the criteria to be met by each technology.

The need for a systematic decision-making procedure for the selection of new technologies at the aviation subsidiary company was identified. The report has evaluated, consolidated and adapted appropriate current technology selection methods, to provide the aviation subsidiary company with the best solution that meets their own requirements. The methodology addresses the financial facets of the selection by calculating the fuzzy NPVs for each technology alternative.

A method for evaluating the proposed procedure has also been developed to capture the users' perceptions after a year's implementation. This evaluation uses the same method utilised to capture the perceptions of the current procedure and so a comparison could be made.

7.4. Areas For Future Research

One element that was always in mind on developing a model was the ability for it to be scaled up. The majority of the work in this area would be the addition of more accurate risk assessment and the development of a sensitivity analysis module. The addition of these extra models would be a research report on their own, but the model is still only able to compare similar new technologies that have the same measurable criteria. The development of a model capable of comparing different new technologies with differing criteria would require major research well beyond the comprehension of a single additional report and would probably develop a separate model utilising a different methodology.

One area where the model would benefit further research is the inclusion of risk analysis and confidence in a reported selection. The main advantage of the additional tool would be the added dimension given to decision-makers to further develop technologies or focus on certain criteria for particular technology. By including risk analysis it would expand the model scenarios and give the business decision more robust fundamentals to be based on.

At present the model produces a selection result that does not detail what would happen if elements of this selection criteria were changed, for example investment costs. It is recommended that a sensitivity analysis is performed using the methodology proposed by Triantaphyllou and Sanchez (1997). Considering a decision problem with M alternatives and N criteria, the minimum change required in the weight of a criterion can be calculated that will cause rank reversal among alternatives. The results will confirm the robustness of the model as it should be seen that several changes must occur simultaneously in the relative weights or the probabilities of occurrence before any rank reversal. Furthermore, the rank reversal for one decision-maker should not necessarily result in reversal of final project rankings.

8. Conclusions

This report presented a methodology to assist aviation companies in their decisions for the selection of new technologies. Previous research has shown that there are a number of areas that are being developed for selecting technology alternatives but that the aviation sector is lacking the application of such methods. If a company has the resources available to have a large committee of decision-makers then a model such as CROSS (consensus-ranking organisational-support system) by Tavana (2003) could be utilised, as is the case with NASA. But if a company cannot accurately quantify criteria then a methodology that utilises fuzzy logic is thought to be more suitable.

The procedure that the aviation subsidiary company could use to assist selecting new technologies was developed. This utilised all the previous work and delivered a documented frame-work that decision-makers could follow and a computer based model developed in Microsoft Excel that provided additional support to the recommended methodology.

A case study verified that the model behaved how it was predicted, although it was understood that an actual result was difficult to verify as once selected only that one technology would be developed further. Further research is recommended to benefit some areas and there will always be further improvements that can be made as has been described in the future research section of this report.

The use of this model is not intended to manage the day to day decisions incurred in a manufacturing facility, but is ideal for developing strategies for future products that are only in the concept stages of development. As a final statement, this model is ideal if used in the correct environment and together with the known limitations of the model will be an invaluable tool in the decision-maker's portfolio.

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