# Theoretical Optimisation of IT/IS Investments : A research note

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**ABSTRACT**

**The justification of Information Technology (IT) is inherently fuzzy, both in theory and practice. The reason for this is due to the largely intangible dimensions of IT projects. In view of this, this research note presents the results of on-going research, in the application of Fuzzy Cognitive Mapping (FCM), as a tool to identify complex functional interrelationships associated with the justification of IT. This paper presents a theoretical functional model which describes these relationships, and by using an FCM, further interrelationships are developed in the context of justifying IT projects. A procedure which would address the optimisation of these intangible relationships in the form of a Genetic Algorithm (GA) is proposed as a process for Investment Justification.**

**Keywords:** Investment Decision Making; IT Evaluation

*Glossary of terms* : DC = Direct Costs, FA = Financial Appraisal, FR = Financial Risks, FUR = Functional Risks, HC = Human Costs, IC = Indirect Costs, IR = Infrastructural Risks, OB = Operational Benefits, OC = Organisational Costs, PB = Project Benefits, PC = Project Costs, RF = Risk Factor, SB = Strategic Benefits, SM = Strategic medium-term benefit, SR = Systemic Risks, TB = Tangible Benefits, TC = Tangible Costs, TL = project lead time, TR = Technological Risks, V= Project Value.

## 1. Introduction

The implementation of new technology is clearly one of the most lengthy, expensive and complex tasks that a firm can undertake (Small and Chen, 1995). In recent years, many sectors of manufacturing, such as aerospace and their related supply chain industries, have been reported as being significant investors in Information Technology (IT) and/or Information Systems (IS) (CEAS 1997 ; Irani *et al.,* 1999a). The superconvergence of many forms of on-line, remote and mobile computing devices means that investing in new IT projects is becoming a significant matter of concern (Farbey *et al.,* 1993; Willcocks, 1994; Butler, 1997).

The level of investment and high degree of uncertainty associated with the adoption of such capital expenditure therefore implies that issues involving project justification should assume great importance (Primrose, 1991).

To highlight this fact, the use of a Fuzzy Cognitive Mapping (FCM) is used in this paper to elucidate some of the key interrelationships involved in these types of decisions. The relevant parameters are outlined in a the form of functional equations in Section 3. Subsequently, an FCM of these variables is shown in Section 4. The use of such a mapping allows a basis for developing search space parameters which will be shown to be part of an investment justification optimisation problem. The search for optimal values relating to this problem can be achieved through an evolutionary approach in the guise of a Genetic Algorithm (GA), as proposed in Section 5 of this paper.

Although this paper reports the results of work in progress and outlines a proposed justification model, the authors intend in the future to identify the necessary variables through empirical case study research, results of which will be subject to a future publication.

## 2. A brief review of investment decision making

The efficient management and operation of business processes are considered closely aligned with the development of a comprehensive IT/IS infrastructure. Industry's innovative development of IT/IS in manufacturing is evident in its evolution, from a limited data processing perspective, to an expanded organisational-wide scope of manufacturing computer-based activities, where information is recognised as a corporate resource, with much potential to improve strategic and operational processes. Therefore, it would appear that during the evaluation process, there is much need for suitable mechanisms that can acknowledge the 'full' implications of an IT/IS deployment. The consideration of such issues; constructs for success, clearly needs developing, as it supports investment decision making. Hence, facilitating a rigorous evaluation process.

This is crucial, as the absence of such a criterion may be affecting the success of many IT/IS deployments. Also, organisations are appreciating the significance of human and organisational factors, and seeking to address these factors, as their contribution is acknowledged as supporting the successful deployment of IT/IS (Meredith, 1987).

In addressing the need for structured evaluation tools, many researchers have approached investment decision making from a variety of perspectives. Much of this effort has been focused on developing a 'single' generic appraisal technique, which can deal with all types of projects, in all circumstances. This has resulted in the development and use of the widely known 'traditional' appraisal techniques (Farbey *et al.*, 1993; Irani *et al.*, 1999b). As a result, it would appear that more attention has been focused in recent years on prescribing how to carry out investment appraisal, rather than taking a holistic view of the evaluation process, which identifies those factors that support the rigorous evaluation of IT/IS.

Previous research showed that the evaluation of IT/IS projects is essentially an optimisation problem that requires the maximisation of strategic and operational benefits (Irani and Sharif, 1997). Within this holistic model, the adoption of human operational factors and risk management was included. This paper revises these assumptions raised in the latter work and as a result, the following points must now be borne in mind :

- Indirect costs need further definition in terms of human and operational costs (re-engineering and re-training);
- Risk review cannot be achieved until a project is implemented and evaluation can be carried out *in-situ*;
- Financial appraisal techniques themselves require quantification within the context of the project being evaluated;
- Strategical and Operational benefits appear to be more tangible (although non-finanical) .
- Indirect costs appear as a major component of project costs.

These points are now extended and expanded into the generation of a revised conceptual model that is then used as the basis for an improved problem for optimisation.

# 3. Conceptual Model for the Justification of IT Projects

The authors of this paper propose the development of a more systematic approach to justifying IT based on the exploration of the limitations of traditional appraisal techniques (Irani *et al.,* 1999b). It is considered that this can be achieved through the use of a functional model, which identifies the various issues involved in the justification of IT. The functional model presented below goes some way to conceptualising the phenomena of investment justification, and focuses on a number of key justification criteria; value, project benefits, project costs, financial appraisal, and project risks.

The following are details of the model. The investment justification process can be succinctly encapsulated within the following expression:

$$JC = f\,[V,\ FA,\ RR] \qquad (1)$$

where *JC* are the justification criteria, *V* is the project value, *FA* is the financial appraisal of the project and *RR* is the post-implementation risk review of the project.

The aim of many justification processes is to identify a relationship between the expected value of an investment and a quantitative analysis of the project costs, benefits and risks.

This model is now discussed in more detail, to obtain more insight into the parameters and their influence in the justification of investment projects. In what follows, explanation of equation variables relate to those described in equation (1) and terms further defined in the glossary.

## 3.1 Project Value

Measuring the perceived value implications of an investment project is a highly subjective process. In order to assess the implications impacting on the value of an investment, the concept of value assessment needs to be introduced. This can be given as the relationship between benefits and costs together with the implication of risk, which is proposed by the authors as :

$$V = f\,[(PB/PC)\,.\,RF] \qquad (2)$$

## 3.2 Project Benefits

Project benefits are an integral part of any investment justification processes. Until recently, the focus has predominantly been on achievable tangible operational benefits. The reason for this is largely due to the simplicity of quantification, in relation to their values. However, the failure to include strategic benefits in many traditional justification frameworks is largely due to their intangible nature.

Since many IT investments now often deliver benefits of a strategic nature, their inclusion in any justification framework is essential. Hence, the holistic implications of project benefits can be denoted for both strategic benefits, *SB*, and operational benefits, *OB*, as:

$$PB = f\,[SB,\ OB] \qquad (3)$$

## 3.3 Project Costs

Project costs encompass both the financial and non-financial implications on an investment. Traditionally, much emphasis has been placed on accounting for the direct project costs of an investment, even though much research suggests that these cost factors are largely underestimated (Irani *et al.,* 1997).

However, it is the indirect cost implications of an investment which clearly need integrating into a robust justification framework. The reason for their inclusion is emphasied by Hochstrasser (1992), who suggests that indirect cost factors maybe up to four times as high as direct project costs. The holistic project cost implications of an investment can therefore be expressed as:

$$PC = f\,[DC,\ IC] \tag{4}$$

where *DC* are direct project costs. Furthermore, a functional relationship for the indirect costs can be attributed to *HC*, human costs, and *OC*, organisational costs :

$$IC = f\,[HC, OC] \tag{5}$$

Indirect costs are largely difficult to define (Irani *et al.,* 1997). Because of this intangible aspect, *IC* is assumed to have an equal, or indeed greater, relevance than *DC*. Indeed, indirect costs can be up to 4 times greater than direct costs as stated by Hochstrasser (1992).

## 3.4 Risk Factor

There is inevitably a risk factor associated with the adoption of any IT project, with Griffiths and Willcocks (1994) suggesting that the degree of risk and uncertainty increases with the size of IT deployment. Therefore, risk management should be considered as an integral part of any holistic justification criteria and must be carried out over the life cycle of the IT project (Hahen and Griffiths, 1996).

Using the life cycle process described by Yeate (1991), a projects' risk factor can be represented mathematically as the relationship:

$$RF = f\,[RI,\ RA] \tag{6}$$

where *RA* is the risk assessment and *RI* is the risk identification. The latter can be considered as the initial stage in the process of determining the risk factor and in defining the financial and strategical boundaries of the project. Hence, the functional relationship of risk identification can be represented as:

$$RI = f\,[FR,\ TR,\ IR,\ FUR,\ SR] \tag{7}$$

where *FR* are the financial risk implications of the project, *TR* are the technological risks associated with the project, *IR* is the corporate specific infrastructural risk, *FUR* is the functional risk of the system and *SR* is the systemic risk.

The second variable in the risk factor equation (6) is that of risk assessment. This is a process where an arbitrary value is assigned to each identified risk along with its significance. This can be done through a number of methods, such as the Analytical Hierarchy Process (AHP) (Saaty, 1980).

The third and final variable in the risk factor equation (6), is the risk review process. This is carried out at the end of the projects' life-cycle, through which the effectiveness of a risk assessment exercise can be traced. The risk review process also provides an opportunity to culminate the relevant sources of risk knowledge into a risk file (Hahen and Griffiths, 1996).

## 3.5 Financial Appraisal

Many traditional investment decisions are made on the limited basis of financial appraisal. The reason for this is because organisational capital budgeting processes often rely exclusively on conventional appraisal techniques. However, the major limitations in using traditional appraisal techniques are that these methods are unable to accommodate the intangible benefits and indirect costs associated with an IT deployment.

Kaplan (1986) explains that many companies who use such predictive methods may be on the road to insolvency, if they consistently invest in projects whose financial returns are below their capital costs. It is not the intention of this paper to be prescriptive in recommending an appraisal technique, but rather offers a descriptive functional relationship of financial appraisal.

Therefore, a financial relationship has been integrated into the justification criteria identified in equation (1) and can be represented analytically as:

$$FA = f\,[TC\ ,\ TB]\ .\ f\,[RF] \tag{8}$$

where *FA* is the company preference financial appraisal technique, *TC* are the tangible cost implications, *TB* are the tangible benefit implications and *RF* is the risk factor associated with the project.

# 4. An FCM of the Justification Process

The proposed functional representation of the IT justification process has been shown to consist of a large number of variables, some of which cannot easily be quantified. The subjective aspect of this process, limits the effective optimisation of the given variables. This also restricts the methodical evaluation of justifying these forms of investments. Additionally, the varying nature of IT/IS projects, means that the entire justification process forms a complex adaptive system subject to external, as well internal, influences.

In previous work, the Fuzzy Cognitive Mapping (FCM) of this problem shown in Figure 1, was proposed by the authors (Irani and Sharif, 1997), to outline the inherently complex interrelationships between the previously defined equations given in Section 3 (Sharif and Irani, 1997).

Such mappings have proved useful in analysing interrelationships within complex adaptive systems which cannot normally be described via traditional 'flow-graph' methods (Kosko, 1990; Simpson, 1990). Such methods traditionally rely upon orthodox notions of input and output states for a prescribed set of discrete conditions

(Mentezemi and Conrath, 1986). Instead, the associative nature of an FCM allows localised parameters to be attributed with fuzzy / vague quantifiers in the form of words or numerical weights. The positive (+) and negative (-) signs which connect each fuzzy concept, denote causal relationships in terms of descriptors, which in this case mean 'has greater effect on' and 'has lesser effect on' respectively. Fuzzy terms are additionally used to delimit the meaning of causal relationships. For example, '+ often' would be read as 'often has greater effect on'. In the context of this paper, causal modifiers relate directly to identifiable characteristic components which can be identified from the literature (as identified in section 2).

The inclusion of additional parameters into the mapping is simple and re-appraisal of interrelationships can be carried out in a straightforward manner. As such, these mappings FCM can provide a holistic view of a set of inter-related paramters.

Since no hierarchical relationship exists between each fuzzy concept / parameter, this type of mapping can be read in an arbitrary fashion. However, in order to highlight a particular interrelationship within the map, a starting or root concept should be chosen from which other fuzzy concepts can be related via the given causal relationship between them.

As an example, we can readily summise the relationship between Project Benefits and the other parameters in the following manner. Project Benefits (*PB*) have increasing effects upon a projects' value (*V*), i.e. '+ highly valued'. *PB* also provides an effective input to the assessment of risk (*RF*), i.e. '+ consistent benefits'. The financial appraisal of project (*FA*) is also greatly enhanced by tangible project benefits, i.e. '+ attractive'. A negative causal relationship exists between project costs (PC) and value (V), i.e. '- high PC', which translates to the rising cost of a project decreasing its overall worth. n such a way, the remaining fuzzy concepts can be related to one another by reading and assessing the fuzzy quantifiers between them.

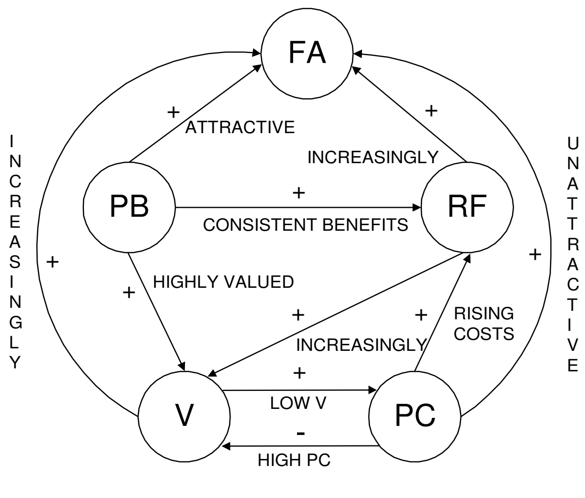


**Figure 1. Fuzzy Cognitive Mapping (FCM) of investment justification criteria**

# 5. Modelling the evaluation of IT/IS projects

As outlined in the preceeding sections of this paper, investment justification is a larger problem than it first appears to be. Through the use of the non-linear directed fuzzy map (given in Figure 1), it can be seen that although largely financial appraisal techniques drive the process forward, issues of risk and cost/benefit payoff are still major hurdles to qualitative evaluation of IT/IS projects.

Indeed, a discussion and analysis of softer issues relating to human and organisational aspects, arising from the functional decomposition of the constituent parts of investment justification, is a matter for extended and progressive research beyond the scope of this research note.

As described in earlier work by the authors, an initial viable assumption to modelling this process is to describe project costs and strategical benefits as part of an optimisation problem, where the minimum difference between costs and benefits is to be achieved (Irani and Sharif, 1997). Project risks are subsequently also assumed to be quantifiable and subject to assessment via traditional risk management techniques.

A closer inspection of this assumption reveals that the viability of accurately decomposing project costs and strategical benefits relative to capital budgeting requirements, does not provide adequate modelling data in terms of an optimisation problem. The authors note that the strategical and operational benefits are to be maximised with respect to statically determinate or increasing project costs. The neglection of this fact, was seen to be a critical limitation of the initial optimisation model proposed in the earlier work (Irani and Sharif, 1997).

A re-hypothesis of the key functional relationships outlined in Section 3 of this paper, has lead the authors to believe that the main optimisable functions should relate to those concerning direct and indirect costs (*DC* and *IC*) and short, medium or long-term strategical benefits. In the following sections, a traditional investment approach is compared to a new pre-emptive model, which for the purposes of this paper, involves a medium-term strategic outlook (i.e. *SM*). To this end, an analysis of the interplay between the *IC*, *DC* and *SM* variables allows the generation of an optimisation problem to be formed in Section 5.3.

## 5.1 Orthodox investment approach

Proceeding a financial appraisal, the implementation of an IT/IS project involves the gradual introduction of new technology in the form of software and hardware. These direct costs, *DC*, are incurred for a finite period after which there is no further activity until another project is initiated and the process starts again. In order for the newly invested technology to be of benefit to an organisation, re-engineering, re-training and development of users of the IT system will have to be carried out.

As previously noted in Section 1, indirect costs, *IC*, are usually 4 times greater than direct costs and often occur well after new technology has been introduced. Thus the lead time from implementation and investment to strategical benefit payoff, $T_L$, is often extended beyond the return on investment period. This phenomenon is shown in Figure 2 below, which shows a single project occuring within a finite time. Additional or complimentary projects may occur on a sequential basis from each other in this respect.

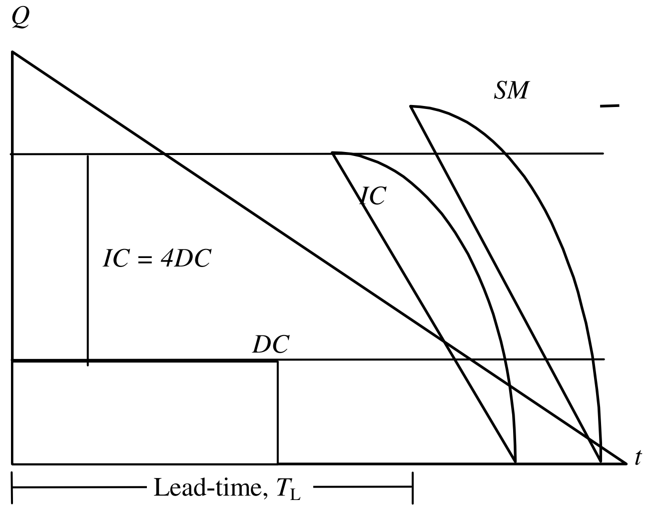


**Figure 2. Orthodox implementation of an IT/IS project**

In other words, tangible benefits occur well after technology has been introduced. These benefits appear to conflict with indirect costs, such that overall organisational benefits tend to be reduced, simply as a result of the time taken to install, customise and train personnel to use new technology.

## 5.2 A Pre-emptive justification model for optimisation

It can be seen from Figure 2, that indirect costs occur well after direct costs are incurred, almost to the negation of medium-term strategical benefits. This state of affairs is widely known to occur in many IT/IS projects and is the basis of many such project failures. To counter-attack this problem, the authors propose a pre-emptive investment model in which the indirect costs are partially subsumed within direct costs, thereby making strategical benefits to occur within a shorter lead-time and at a potentially higher magnitude.

In simple terms, this ultimately means a phase shift of the relationship between *IC* and *DC* which is shown in Figure 3 below.

Hence for successful implementation and evaluation of IT/IS projects, indirect costs should be determined such that they coincide and occur with direct costs, whilst also decreasing the lead-time between initiation and completion of a new project. Essentially such a problem decomposes into a three-stage optimisation whence it is required that :

$$\min \{IC\} \text{ subject to } DC \quad (9)$$

$$\max \{SM\} \text{ subject to } DC \text{ and } IC \quad (10)$$

$$\min \{T_L\} \text{ subject to } SM = \min \{IC\} \quad (11)$$

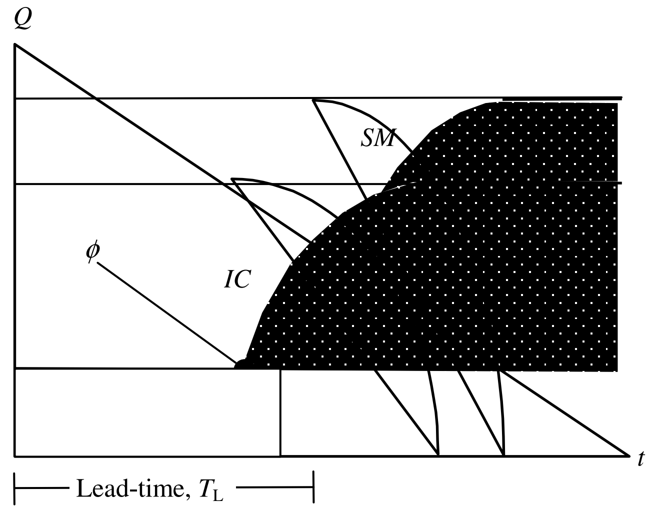


**Figure 3. Pre-emptive investment model for IT/IS projects**

Equation (9) relates to the minimisation of the shaded area and equation (10) relates to the maximisation of the area . Also, for the purposes of the hypothesis within this paper, the lead time, $T_L$, is dependant upon the magnitude and introduction of indirect costs, *IC*, in equation (11).

The point of intersection between *DC* and *IC*, $\phi$, is of particular interest to the optimisation which is required. This essentially defines the point where *IC* equals *DC* and can be viewed as the *minimum cost realisation*. This is a point beyond which, indirect costs increasingly affect strategic benefits. The location of this point is not considered within the scope of this paper, and is a matter for further research.

## 5.3 Optimisation via a GA

The multi-parametric optimisation problem given in equations (9)-(11) can be decomposed into a functional relative to the distance metric between *DC*, *IC* and *SM*. This can be written as the theorectical expression for optimal investment justification, *IJ*:

$$\begin{aligned} IJ &= \min \{IC, T_L\} + \max \{SM\} \\ &= \min \{4DC, T_L\} + \max \{SM\} \end{aligned} \quad (12)$$

Since no numerical data currently exists for these variables, an approximation in the form of the following discrete transcendental functionals can be made (13)-(15):

$$DC = \tanh(t) \tag{13}$$
$$IC = 4\tanh(t) \tag{14}$$
$$SM = 1 - \exp\left(\log\frac{1}{t}\right) + \alpha \tag{15}$$

where $\alpha$ is a constant which locates *SM* above the positive quadrant *x*-axis and also it should be noted that *IC* is generally four times greater than *DC*. Noting the hyperbolic form of equations (13) and (14), equation (12) can be rewritten as:

$$IJ = \min\left\{16\tan^2 \mathrm{h}(t)\right\} + \max\left\{1 - \exp\left(\log\frac{1}{t}\right) + \alpha\right\}$$

$$= \min\left\{\exp\frac{1}{t}\left(16\tanh(t) + \left(1 - \log\frac{1}{t}\right) + \alpha\right)\right\} \tag{16}$$

This equation relates the curves of direct and indirect costs to strategic medium-term benefits. The multi-objective nature of this means that gradient-based search techniques will be better at finding a locally optimal minimum of these variables. This is an adequate result should there be a dominating parameter or set of parameters within the problem which requires minimisation or maximisation. Hence global optimisation strategies, such as Genetic Algorithms (Goldberg 1989) which rely on paramter encoding and manipulation via Darwinian notions of evolution, have been steadily growing in popularity and application. Through such a technique the definition of subsequent modifying parameters (as shown by the FCM in section 4) can be represented straightforwardly as part of the optimisation strategy through a representative encoding scheme (i.e. binary or real-valued bit strings).

In the area of investment decision making and optimisation, little work has been carried out with regards to the application of enumerative search methods. Research that has been carried out mostly centres around the optimisation of maximising the benefits of stocks and investment portfolios (Bauer, 1994 ; Vedarajan *et al.,* 1997) or in financial forecasting (Kassicieh *et al.,* 1998). Generally, these genetic algorithms (GAs) have been used to provide bounds on the return on investment, associated risk and transaction cost of the shares for a given size of portfolio. The nature of GAs mean that payoff-only results are found for a given population size and objective function (Holland, 1992). This translates to finding the minimum value of *IC* such that a maximum value of *SM* will occur.

For the case of the research area under investigation in this paper, the criteria under evaluation can be said to be non-dominant of one another. This defines the problem as being of a Pareto-optimal type, such that evaluation of each individual criterion is summarily as important as any other one, in some respect. This can present a problem in terms of defining an objective function within a GA, since the multiobjective nature of a pareto-optimal problem means that the search path may come across a highly optimal solution in terms of a single parameter, whilst degrading the 'performance' of other interrelated quantities. Methods to overcome this include ranking the objective function in terms of its commensurate parts, or by ensuring that there is a limited relationship between variables contained in the function (Bentley and Wakefield 1997, Goldberg 1989). As such further investigation into the functional description of the investment justification model, would highlight this aspect of modelling the evaluation process via GAs.

# 6. Concluding Remarks

This paper has revised and discussed the on-going research of the authors with respect to the modelling and analysis of IT/IS investment justification. Traditional appraisal techniques focus on non-strategic, short-term, tangible benefits, with the 'larger picture' often missing from the formal justification process.

It was verified that such a process is a complex task, even after interpreting the causal relationships found via a Fuzzy Cognitive Mapping (FCM) of the problem. Hence by increasing the level of known data about such a vague and, to some extent, intrinsically incalculable problem, a causal route to justifying a project can be found via a fuzzy cognitive map.

The subsequent reappraisal of the optimisation of indirect costs and strategical benefits, lead to the generation of a pre-emptive investment justification model. This model describes the optimal conditions for successful project implementation, and hence defines the boundaries for a projects' evaluation. These additional perspectives consider the business value of the investment, monitor the performance of the project, and keeps it aligned to the organisational strategy. Further application of fuzzy logic could clearly avoid some of the difficulties encountered while using traditional approaches to project justification.

The minimisation of indirect project costs for a given maximisation of medium-term strategical benefits, was seen to be a candidate problem for an enumerative, evolutionary search. Investment evaluation seems to consist of a series of broad optimisation criteria.

Currently, no case study data exists which can be used as a basis to verify and develop the hypotheses contained within this paper. Therefore, the decomposition of these variables into modified transcendental functions gives a prospective objective function which can be used for a genetic-algorithm based search for the optimum values of *IC* and *SM*.

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## 7. Future Work

From the discussions provided in this research note the authors propose continuation of this research along the following lines :

- Development of case study strategy to identify costs, benefits and risks (including soft organisational issues).
- Assignment of appropriate evaluation / fitness criteria for the genetic algorithm approach, based on industry findings (context and expert knowledge-sensitive).
- Investigation of the location of minimum cost realisation, i.e. when indirect project costs start to affect project benefits and associated pareto-optimal aspects (when $SM = IC = DC$ for example).
- Analysis of the genetic algorithm approach to optimise factors within the Investment Justification process.
- Prediction and evaluation of implications arising from such approaches to investment decision making, for industry (comparison with other frameworks and methodologies).

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