Shortening the Decision Distance: selecting decision aids for improved technology investment performance

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Abstract

Deciding which technology to invest in is a recurring issue for technology managers, and the ability to successfully identify the right technology can be a make or break decision for a company. The effects of globalisation have made this issue even more imperative. Not only do companies have to be competitive by global standards but increasingly they have to source technological capabilities from overseas as well.

Technology managers already have a variety of decision aids to draw upon, including valuation tools, for example DCF and real options; decision trees; and technology roadmapping. However little theory exists on when, where, why or even how to best apply particular decision aids. Rather than developing further techniques, this paper reviews the relevance and limitations of existing techniques. This is drawn from an on going research project which seeks to support technology managers in selecting and applying existing decision aids and potentially in the design of future decision aids. It is intended that through improving the selection of decision aids, decision performance can be increased, leading to more effective allocation of resources and hence competitive advantage.

I. INTRODUCTION

This paper is concerned with the process of deciding which technology to investment in. More specifically it relates to the evaluation techniques that can be used to assist internal decisions regarding individual R&D projects. The use of "technique" is in its most generic sense and includes specific tools e.g. Discounted Cash Flow (DCF); methods and approaches e.g. options thinking.

The need for effective technology evaluation techniques has risen with the ever increasing rate of technical change observed in the second half of the 20th century [1]. Simultaneously, technology has played an increasingly significant role across all economic sectors. As long ago as 1957, Griliches recognised the role that technology plays in macro-economic growth [2]. The last decades of the 20th century also saw a shift towards a knowledge based economy [3]. Drucker [4] notes that in such an economy: "Land, labor, and capital – the economist's traditional factors of production – do not disappear, but they become secondary". Rather, the need now is for rapid and flexible innovation as a source of competitive advantage [5] and as Lev notes "Abnormal earnings are the result of either monopoly power or more frequently-innovation" [6].

The trend towards globalisation has further increased competition with firms now having to embrace global best practices. This is combined with a further emphasis on maximising shareholder return [7] and more rigorous and analytical attitudes towards risk and its management [8-10]. The result is a need to enhance the strategic management of innovation. The combined scenario is one in which there is a requirement not only for increased innovation but also the effective spending of budgets allocated to its achievement. As Leuhrman [11] observes, "Behind every major resource-allocation decision a company makes, lies some calculation of what that move is worth".

Currently reviews of tools for technology management tend to be high level with little insight into implementation issues [12-15]. Specifically in a benchmarking study; over 50% of respondents reported that the most pressing need for improving R&D performance was developing an improved decision process [16] in [17].

Implicit within technology evaluation is its role as a decision aid, where decision aid refers to an explicit procedure for the generation, evaluation and selection of alternatives that is designed for practical and multiple use [18]. Moreover, adopting a systematic approach is assumed effective in avoiding common reasoning errors and potential pitfalls in decision-making [19]. Bell et. al [20] define three approaches of decision aids: normative, descriptive and prescriptive. Technology evaluation techniques are arguably a prescriptive aid, which is defined as "…theories and associated experimental evidence and field studies concerned with helping decision makers improve their performance in problem finding and problem solving, given the complexities and constraints of real life" [21].

The emphasis of this paper is to introduce concepts that have emerged from, and now form the basis of, ongoing research. Thus far, a pilot-study consisting of 10 minor case-studies has been performed. The aim of the ongoing research is to understand the comparative contribution of inductive and deductive reasoning to technology investment decisions and how this changes with technology maturity. The objective is to develop understanding that can aid managers in selecting and applying existing techniques and also in the design of future decision aids.

The remainder of this paper is divided into three sections. The first section proposes a development on Algie and Wolfers' taxonomy [22] that uses "information processing" and "thought processing" as a means to differentiate between current techniques. It is argued that the distinction between evaluation techniques is ultimately based on the type of reasoning (i.e. deductive vs. inductive) evoked. The second section introduces the concept of the "Decision Distance" as means to explain A) the (in)appropriateness of applying certain techniques to particular settings and B) the observed preference of technology managers to use subjective and qualitative approaches in early-stage decisions. The third provides a review of current technology evaluation techniques and seeks to relate their use to the perspectives provided above. The fourth section outlines the research approach employed.

II. INFORMATION PROCESSING VS. THOUGHT PROCESSING

A. Data as the basis of decisions

Data may form the basis of many, if not all, decisions. However, it is important to note that although necessary it is not sufficient on its own for decision-making: "Data is a set of discrete, objective facts about events…Data describes only a part of what happened; it provides no judgment or interpretation and no sustainable basis of action…Data says nothing about its own importance or relevance." [23]. Indeed several authors refer to a knowledge hierarchy where "data are understood to be symbols which have not yet been interpreted, information is data with meaning, and knowledge is what enables people to assign meaning and thereby generate information" [24], p.13 in [25].

The emergence of an economy based on knowledge was first commented on by Drucker [26] in the late 1960s and obtained popular acknowledgement in the final two decades of the 20th century. Such an environment requires both suitable data upon which to base decisions and also the means to process it. Algie refers to the techniques used to handle data and information relevant to decisions as "information processing methods" [27] in[22]. However the use of these information processing methods alone may be insufficient at times: "…most difficult complex issues have at least residual features that cannot be handled solely by information-processing" [22]. In such circumstances, alternative methods need to be employed with Algie and Wolfers [22] noting the existence of "thought processing" techniques. These permit decision-makers to "…manipulate their relevant ideas, thoughts, and qualitative valuation judgements" [22] and use these techniques to "establish a framework, model or structure within which to handle the issue" [22].

In their paper [22], Algie and Wolfers developed a taxonomy for thought processing and information processing techniques. The techniques are clearly designated into six categories; three for information processing (investigation, intelligence, and communication) and three for thought processing (decision insight, decision advice and planning and evaluation) - examples of these can be found in the original paper. They also comment that certain categories are more suitable for certain settings than others but that at present, the use of certain techniques over others is determined more by decision-makers' existing familiarity with the technique than by a reasoned choice.

Cohen and Nagel [28] in [22]observed that noting and classification are prerequisites for the construction of theories and more commonly recognised laws. This paper is part of ongoing work that seeks to develop guidance on the application of decision support techniques in the specific case of technology evaluation, and the contribution of Algie and Wolfers' taxonomy is duly noted. However an alternative perspective is taken here. Whilst it is recognised that a distinction between information and thought processing does indeed exist, the author is not of the opinion that in the case of technology evaluation, techniques should be categorised as either one or the other. Rather, it is proposed that technology evaluation techniques have a capacity for both information and thought processing but in varying degrees across a continuum.

B. A spectrum of ideas

Having introduced the concept of a continuous spectrum instead of discrete categories, this section seeks to demonstrate how this applies to technology evaluation techniques. Figure 1, aims to provide an outline illustration; it is not intended as definitive or even a calibrated scale of the techniques displayed.

Insert Figure 1 about here.

At the predominantly information processing end of the spectrum, lies the Discounted Cash Flow (DCF). As a result of its quantitative nature and point value output, the role of DCF is largely to synthesise a large quantity of data into a manageable form for decision-makers. However, despite its role as a data synthesiser it also displays some tolerance to being employed as a thought generator. For example, it can also be used to structure thinking in terms of expected market size, market share, latent need fulfilled etc. As Algie and Wolfers note "…decision-makers may use some decision methods with quantitative components to tackle 'qualitative' aspects of issues" [22].

At the other end of the spectrum lies open brainstorming where a session will typically involve only the thoughts generated by participants. These thoughts are likely to be expressed in a qualitative form and are obviously entirely subjective. However, brainstorming sessions can also be assisted by corporate information systems; this represents their capacity for processing objective information.

At approximately the halfway point, lie the portfolio ranking and scoring methods. These will vary considerably in form between companies but are ultimately similar in i) essence; a means to evaluate R&D projects along multiple dimensions and ii) purpose; "The basic idea of this class of models is to solve the commons dilemma: That the collection of several local optima is not itself optimal" [29]. In producing a relative valuation, a significant amount of data may be subjectively generated (i.e. by thought processing) but this information is subsequently processed to produce a quantified output on which to base decisions (i.e. information processing).

In these three examples, it also appears that a technology evaluation technique does not exist as a point on the information to thought processing spectrum but rather each technique occupies a range of values. Some other interesting aspects begin to emerge:

- The objectiveness of the data used
- The nature of qualitative and quantitative techniques
- The actual role of information and thought processing to decision making
- These aspects are considered in more detail in the following sub-section.

The first aspect to consider is the objectiveness of the data used. DCF can be considered the most objective and brainstorming the most subjective. However the position taken in this paper is that the level of objectiveness is not that of its philosophical (ontological) context but rather is relative to the decision-maker(s). Ontologically objective would imply an external, independent and measurable reality. It is diametrically opposed to the concept of social constructivism. In DCF, all variables from hurdle rate to market size have been determined by human interaction and therefore it does not make sense to refer to DCF as ontologically objective. However, objective is defined here to mean that the information originates and is accepted externally to the decision-maker(s). For example, when used for its output, DCF is objective relative to the decision makers in so far that information has been generated (subjectively) but previously and externally to the decision-making process. It may also be that such information has a certain degree of collective acceptance i.e. outside of the actual decision-making and moreover the information would be available to any other decision- maker(s). This is in contrast to a brainstorming session in which the information used is internal to the decision-makers, may originate in a tacit form and may not have widespread acceptance. Furthermore, it is through the very process of performing the technique that knowledge required for decisions may be generated. The generation of knowledge implies an outward flux of information from the technique. This is again in contrast to the information processing end of the spectrum, where the flux is in an inwards direction i.e. from externally available "objective" data into the technique.

On the basis of the discussion above two factors begin to emerge as determining the position of a technology evaluation technique on the information processing to thought processing continuum:

1. The objectiveness of the data relative to the decision-maker(s)
2. Whether the technique is used for the output it produces or whether the emphasis is merely on the process employed in applying the technique.

For example, in the case of the latter factor, DCF will commonly be used for its output whereas much of the benefit of brainstorming is in the very act of performing it. It is also possible that positions somewhere between these two extremes (i.e. process and output) may be possible.

Now let T represent the type of data i.e. how objective/subjective it is; let M represent the method i.e. the use of a technique for its output or process and let C_P be the position on the information to thought processing continuum. Then from the above:

$$C_P = f\,(T,M)$$

A further factor is also present; the representation of the data i.e. in qualitative or quantitative form. This is considered independent of how objective that data may be (i.e. T) and also whether the technique was used for its output or for the process (i.e. M). For example, the size of a potential market may be estimated within a decision-group (i.e. subjective) but be represented as a quantity. Similarly, in assessing how well an R&D project is aligned to corporate strategy, this strategy would be expressed qualitatively but be external to the group (i.e. objective).

It is noted however that a strong correlation exists between i) the qualitative representation and thought processing techniques and ii) the quantitative representation and information processing techniques. It is suggested that the terms qualitative and quantitative refer only to the manner in which data and information are represented. It is also held that the position on the continuum will be dependent on this representation; if we let R be the representation then:

$$C_P = f\,(R)$$

Combining with the previous statement the first proposition of this article is:

Proposition 1 $\quad C_P = f\,(T,M,R)$

It is further proposed that their contribution to actual decision-making is determined by the direction of flux of knowledge. This can be expressed in terms of inductive and deductive reasoning:

Proposition 2 *The position of a technology evaluation technique on the information processing to thought processing continuum is manifested by the degree in which it facilitates deductive to inductive reasoning.*

Using the assumptions from proposition 2, proposition 1 can also be stated as: the degree to which deductive vs. inductive reasoning is facilitated, is a function of the type of data used, its representation and the mode of use of the techniques.

III. THE DECISION DISTANCE

Thus-far we have been concerned with individual decision techniques. In contrast the aim of this section is to approach from an alternative perspective i.e. the task environment in which a decision must occur. In the context of this research, the decisions to be taken concern in-house innovative technology investments. For such decisions, the techniques outlined in Section 2 may provide the basis for decisions or support the process of reaching a decision but are not in themselves the solution to the task. Raiffa [30] observes that decision-makers must use their judgement in interpreting the output of the model and include those factors not considered by the model. For example Chatwin et al. [31] argue that decision analysis cannot be used in investments where market data cannot be identified. Raiffa also refers to the "judgemental gap" between the output of a model and the real world. This is displayed schematically in Figure 2:

Insert Figure 2 about here.

Whereas Raiffa refers to the "judgemental gap", an alternative perspective of this concept is proposed here in the form of the "Decision Distance":

Insert Figure 3 about here.

The main advancement of the decision distance is the decomposition of the "judgemental gap" present in the Raiffa model into multiple dimensions. In the case displayed in Figure 3:

1. The complexity of the problem/situation being considered and the complexity of the model/tool/technique being used to aid the decision.
2. The level of abstraction from the real world present in parameters of the model or the model itself.

(It is important to note that these dimensions were chosen for illustrative purposes only and that other dimensions may exist that contribute to a decision distance e.g. cost and time of implementation).

In essence, the decision distance refers to the discrepancy between the output of the technique and the task at hand i.e. the decision to be taken within a particular context. This distance can arise either as a result of the model being overly simple e.g. DCF; or because it is too abstract to be accepted e.g. the Black-Scholes formula. It represents the amount of interpretation required to implement the output of a particular technique.

Raiffa also recognises that this judgemental gap might be "…so wide that the analysis does not pass the threshold of relevance; the analysis may fall short of furnishing meaningful insights into the problem." [30]. This is displayed in terms of the decision distance in Figure 4. In such circumstances, Dissel [32] notes that "…the uncertainty shifts from the actual calculation and decision to the assumptions on which the decisions are made." This is interpreted to imply that as the threshold of relevance is passed, the mode of operation of the technique changes i.e. it is no longer used purely for its output but rather as a process for generating such an output. This implies that it is the no longer the information processing capacity of the tool that is used but rather its thought processing capacity- "assumptions" are subjective judgements after all. In fact empirical studies by Agor suggest that intuition is most useful in uncertain situations with insufficient facts and complex alternatives [33]. Clarke states that "Intuition seems, therefore, to come more into play as a means of 'going beyond' the rational data and information." [34]. The capacity of an evaluation technique to facilitate inductive reasoning is therefore of importance in promoting the suitable use of intuition.

It may also be that if the technique is so far removed from the task, that a further threshold- that of applicability is also passed. The threshold of applicability is defined as the decision distance above which both the information and thought-processing capacity of a technique has been exceeded. This is also displayed in Figure 4. When such a threshold is passed, the decision would essentially be based on guesswork and decision performance likely to be critically diminished.

Insert Figure 4 about here.

Interviews with technology managers, performed as part of a pilot-study consisting of 10 minor case-studies, have shown a general preference for more subjective and qualitative evaluation techniques in the earliest stages of technology development i.e. those stages with high levels of both technical and market uncertainty. It is proposed that in such a decision-environment, a greater degree of inductive rather than deductive reasoning is required. If this is indeed the case, the preference for more subjective and qualitative evaluation techniques can be explained in terms of the decision distance: the use of single-output, financial techniques in the early stages would produce a decision distance too great to be of any practical assistance to decision-making i.e. it would be beyond the threshold of applicability. If true, then:

Proposition 3 *A greater degree of inductive reasoning is present in early-stage decisions than in late stage decisions.*

Proposition 4 *A lesser degree of deductive reasoning is present in early-stage decisions than in late stage decisions.*

In Figures 3 and 4, the real world task is purposely displayed as nebulous. This is predominantly based on two inputs: i) Isenberg's observation that "…when a manager addresses any particular problem, he or she calls a number of related problems or issue to mind at the same time" [35] and ii) Checkland's comment that "…for most managers most of the time both what to do and how to do are problematical." [36]. Pilot-study interviews have also identified multiple and/or ill-defined problems in the context of technology investment decisions.

Although the real world problem/task may escape a precise definition, it will present the decision-maker(s) with certain requirements. Payne notes that "decision making… is highly contingent on the demands of the task" [37]. Furthermore Hammond states that the "properties of the task tend to induce corresponding cognitive properties" and that "the greater the correspondence between task properties and cognitive properties, the greater the subject's achievements" [38], pp.171-2 in[39].

In summary the task defines the requirements and therefore the cognitive process most suitable for addressing it. If the premise derived in Section 2, that different techniques permit varying ratios and degrees of inductive and deductive thought, is true then:

Proposition 5 *Alignment between the technology evaluation technique(s) used and task properties can be expected to improve decision performance.*

Expressed in terms of the decision distance:

Proposition 6 $D_p \alpha 1/D_d$

Where,
D_p = Decision performance.
D_d = Decision distance.

A potential solution to the issue could be to use multiple-methods at each decision point. Whilst Bennett [40] advocates this so that different techniques can be applied where they are most appropriate, Ackermann suggests that "The different methods can inform and enrich one another, providing better models than the individual techniques could elicit on their own" [41].

IV. CURRENT METHODS

Having introduced the concepts of A) a continuum between information and thought processing and B) the decision distance, this section seeks to outline the commonly used technology evaluation techniques and their scope. Reference is made to both the literature and insights gained from interviews with technology managers.

The techniques have been arranged according to three categories:

- Cardinal valuation - based on market, cost or income considerations.
- Ordinal valuation - relative valuation between technology development projects.

- Others - those that are not specific to technology investment decisions but are suitable in certain circumstances.

A. Cardinal valuation

1. Market based approaches

There are two commonly used approaches: industry standards and auction.

Industry standards refer to the use of numerous previous cases as a means to establish value or transaction price. Implicit here is the presence of an existing industrial sector such that its norms and practices that can be considered standards. Razgaitis [42] observes that the key elements are "…published market information, large number of deals, and standards by which quality can be assessed."

An auction refers to the acceptance of sealed bids following the dissemination of the technology's characteristics to a broad range of potential customers [43]. Razgaitis [42] observes that similar to industry standards, auctions rely on direct market determinations. The limitations of the method include the number of participants needed to make the process worthwhile, the need for pre-existing interest from buyers and the effort in communicating the benefits of the technology to bidders.

From the research conducted to date, there appears to be no use of market based approaches for the purpose of internal technology evaluation. The use of an auction is clearly not applicable for an internal decision and industry standards may be inappropriate for an innovation-based setting. This latter point can also be explained in terms of the decision distance: Industry standards, by their very nature, rely on the most collectively accepted (i.e. objective) data. Simultaneously industry standards are used to establish a single point value. Together these imply a very deductive approach. When transposed onto the task of evaluating technologies before they are even incorporated into products, industry standards lie beyond the threshold of applicability.

2. Cost based approach

Here the evaluation is based on the costs incurred in developing or replicating a technology. It is typically used to decide between in-house development and external acquisitions [43, 44] but has not been found to be used in the evaluation of individual technology projects.

3. Income based approaches

Four methods are presented here that make use of a forecasted income as the basis of their calculation. They are DCF, options based thinking, decision trees and derivative based pricing.

DCF methods are built on the relationship between present and future value. Expressed mathematically:

$$\text{Present value} = \frac{\text{Future value}}{1 + \text{Interest rate}}$$

Several authors note that DCF is the most used and widely accepted method of valuation [45-48]. Furthermore it is easy-to-use, widely applicable, and credible [49]. However, myopic use of the technique can lead to poor decision making [7] and risk of undervaluation [50]. These shortcomings resulted in manipulations of cash flows to unlikely levels [49] in order to justify “gut feel”, resulting in a lack of credibility [51].

DCF is very sensitive to the discount factor used [52] and poor accuracy follows with high levels of uncertainty [49]. This uncertainty is penalised by using higher discount rates, even if there is potential to profit from this uncertainty. Value can sometimes be obtained through waiting for more complete information [53] because projected revenues, growth rates and discount rates are assumptions and data may simply be unavailable for early stage technology projects [48].

In the interviews conducted thus far, DCF was by far the most commonly used technique. However, the mode of use varied considerably: from an unquestioning reliance on the output to a means of structuring a brain-storming session. This variance could be explained in terms of the increased inductive reasoning permitted by the process oriented approach i.e. some decision environments meant that the output was beyond the threshold of relevance. For those managers using the output of the DCF, it was frequently noted that the decision was actually based on gut-feel and the figures were produced simply to justify this. This would imply that in these settings the threshold of applicability had been crossed and that the technique on its own was of no influence on an individual decision.

An alternative to DCF is the Real Options approach. The term itself is used to describe a range of ideas [54], from the concept of options (i.e. that uncertainty can have value which can be captured) through to quantitative applications e.g. decision tree analysis and pricing models borrowed from financial markets.

An "option" represents a small investment offering the opportunity to purchase an underlying security at a later date [55]. They create additional possibilities for decisions e.g. waiting [55] or abandonment of investments [56]. Several authors have noted the parallels of financial options and technology /R&D investments [44, 57-59].

Decision tree analysis originates from decision theory [30, 60] and predates the term real options, but nonetheless is now an integral part of options based approaches. It goes further than the conceptual level in that it attempts to quantify options thinking [54] by classifying possible future outcomes and assigning probabilities to these outcomes through a combination of past data and expert opinions. Decision trees also produce clarity and the ability to visualise exactly what information, which decision points and where active management can contribute value.

Fundamental to a decision tree are the outcome probabilities (or “chance nodes”). The reliability (and meaning) of these probabilities is often criticised [61]. In the presence of uncertainty e.g. future market size, decision theory uses subjective probabilities [30, 62, 63]. The success of such decisions thus depends on the capabilities of the decision maker.

A refinement of the decision tree is the Monte Carlo simulation. Instead of attempting to estimate exact parameters, ranges can be used. These should be easier to establish and the main advantage is the creation of a “value range” in place of a point source output.

According to Boer (2002), the application of financial derivative pricing to real assets has its origins in Myers’ (1984) attempt to link strategy and finance. This built on the work of Black and Scholes [64] and Merton [65] in options in financial markets. Brealey and Myers [46] consider that the parallels are sufficient to use the Black-Scholes (B-S) formula for valuing R&D projects. However, real options differ in that financial derivatives are tangible and tradable, whereas real options are usually embedded in opportunities [9], and the non-arbitrage assumption is not valid without a risk-free replicating portfolio [49]. The absence of market also questions the Efficient Market hypothesis and the exponential Brownian motion assumption [49].

In R&D projects, information becomes available at discrete points [49] and decision trees may therefore be a more accurate model [61]. Bollen [66] suggests that the B-S approach is better used when uncertainty starts diminishing and technological applications start emerging.

During interviews it became apparent that not all managers were familiar with the options based approach, although some were implementing certain features of it. For example, one company had recently introduced a "Decision Point Zero" as a means to resolve key uncertainties prior to their stage-gated product development process. The use of the B-S equation was found to be unpopular by those in companies employing it, the most commonly cited reason being its "black box" nature. It is argued that this arises as a result of its reliance on a single value output and the level of abstraction of some terms within the equation. Combined, these factors could be producing a technique which promotes a more deductive approach than that permitted by the uncertainties which it tries to address. The use of decision trees was more popular but by no means widespread. In those instances where they were used, it tended to be in a more informal manner e.g. for the construction of "mental models". This is taken to imply that some degree of a inductive approach is required and that a decision tree is able to satisfy this.

B. Ordinal Valuation

Relative valuation is manifested in the form of ranking and scoring and refers to the selection and prioritisation of technology development projects according to their relative worth for a company and is a role of portfolio management.

Ranking approaches are most widely used when dealing with hard-to-quantify issues [42]. There are methods which build on economic models using decision theory [67] and multi-perspective views [68] but, as some authors have observed [69, 70] they are seldom used in practice.

Whilst many differing ranking methods are applied across industries and countries [71, 72]. Cooper [73] notes that no one way is best, owing to the subjectivity arising as a result of the absence of universal criteria [42]. Whilst Brenner [74] notes that even within a structured process there is still need for judgement because there are always issues to consider that are outside the framework. Ultimately, all applications of ranking/scoring have a common aim: a strategically aligned balance of low risk projects with a few higher-risk opportunities [69].

The use of an ordinal valuation was common in those companies involved in technology development and not just product development i.e. at an earlier stage of technology maturity. An interesting feature was the combination of quantitative data e.g. manpower or financial resources required; with more qualitative aspects e.g. perceived strategic benefit. In one company, it was mentioned that the data were essentially used as benchmarks (i.e. a deductive approach) whilst the qualitative aspects were used to create categories within the portfolio. These categories were said to reduce the range over which an investment decision had to be made. It is suggested here that this reduction in range serves to facilitate inductive decision making. The balance between the two types of reasoning again defines the suitability of the technique.

C. Other techniques

Interviews conducted to date with practicing technology mangers have also highlighted the use of techniques not commonly found in the literature. They tend to be focused on identifying future opportunities and often emphasise the process over the output. Examples include:

- Open brainstorming
- Mind-mapping
- Domain-mapping

A further technique is proposed by [75] in the form of "Value Roadmapping". This technique seeks to identify the various value streams (along a time dimension) that can be created through a combination of emerging market trends and technology development offerings.

The above techniques are highly inductive approaches, with the generation of information being facilitated by the process approach and a favouring of the qualitative representation. In all cases, these techniques were used exclusively in only the earliest stages of decision-making. It is presumed that an absence of pre-existing information prevents the use of more deductive approaches i.e. they are recognised as being beyond the threshold of applicability.

V. Research Approach

This paper serves to highlight some of the conceptual developments as part of ongoing research. This research seeks to understand how the decision-making environment surrounding technology investments changes with technology-maturity.

So far 10 illustrative case studies have been conducted. Each of these studies consisted of semi-structured interviews with multiple decision-makers across the company. The interviews focussed on the techniques currently employed and the process of technology development. The qualitative data collected from these interviews was initially processed through open-coding to establish the concepts. These were then grouped into categories and the relationship between categories established through axial coding. Selective coding was then used to integrate the categories with each other and those identified in the literature. It is acknowledged that 10 case-studies are insufficient to produce generalisations and that the single method of data-collection and analysis limits the validity of initial findings. However useful insights have been gained and have served in the development of the conceptual model. Further research continues to be based on case-studies but will also employ the methods used and proposed by [34]. In this research, case-study companies' stage-gated development processes are used as a proxy for technology maturity i.e. the distinction between early and late stage. For each decision point of a stage-gated development process the following steps are being undertaken:

- Ethnographic observation of group decision meeting.
- Content (textual) analysis of supporting documentation.
- Individual and group cognitive mapping to reveal underlying decision schemas.

The first two data-collection methods seek to establish the attributes of the techniques being used (mode of use, type and representation of data) as well as validating the cognitive maps. If Propositions 1, 3 and 4 are correct then it can be expected that in the first stage-gates, the techniques employed will feature one or more of: a process based approach, the generation of subjective data and qualitative representation of data. In contrast, it can be expected that for the latter stage-gates, the techniques employed will feature one or more of: reliance on an output, the use of previously generated and quantitatively represented data. The use of cognitive mapping aims to identify:

- The complexity of the decision-making environment
- The ratio of factual to non-factual information
- The clustering of concepts
- The length of decision-chains

It is envisaged that the combination of these methods will serve to test propositions 1 to 4 and thus form the basis of further research that can provide guidance on when and where to apply certain techniques.

VI. CONCLUSION

This paper has sought to introduce commonly used evaluation techniques and their scope in technology investment decisions. It has also introduced the concepts of an information-to-thought processing continuum as a means to differentiate between these evaluations techniques. It is argued that this continuum features deductive and inductive reasoning as its two poles. Furthermore, Raiffa's concept of a judgemental gap has been developed into the decision distance and as a means to illustrate the appropriateness of an evaluation technique to a particular decision environment.

Technology managers must continue to face ever tougher decisions when investing increasingly scarce resources. If emerging technologies are going to be used for the betterment of humanity, so that society may be the winner, investments are required in their research, in their development and in their commercialisation. Such investments require decisions to be made in the presence of increasing rates of change and the convergence of previously unrelated industries meaning that rapid decisions need to be reached beyond the limits of existing expertise. In the presence of such conditions, technology managers need support in their decisions. It is anticipated that the contribution of this work will be in the development of guidance for the effective use and design of technology evaluation techniques.

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FIGURES

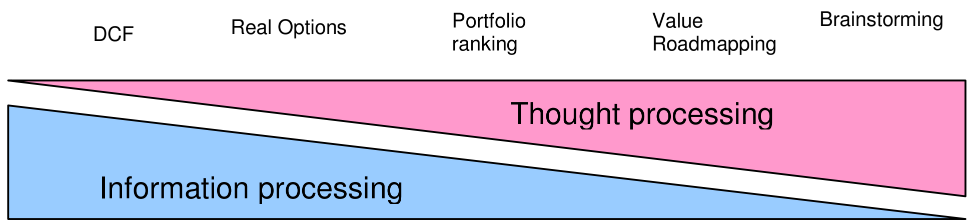

FIGURE 1
The continuum of information processing to thought processing

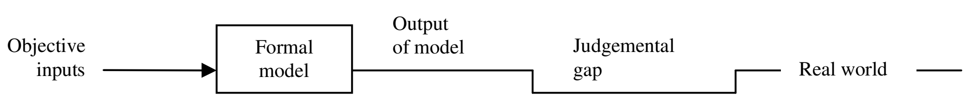

FIGURE 2
The judgmental gap (adapted from Raiffa 1968 p. 297)

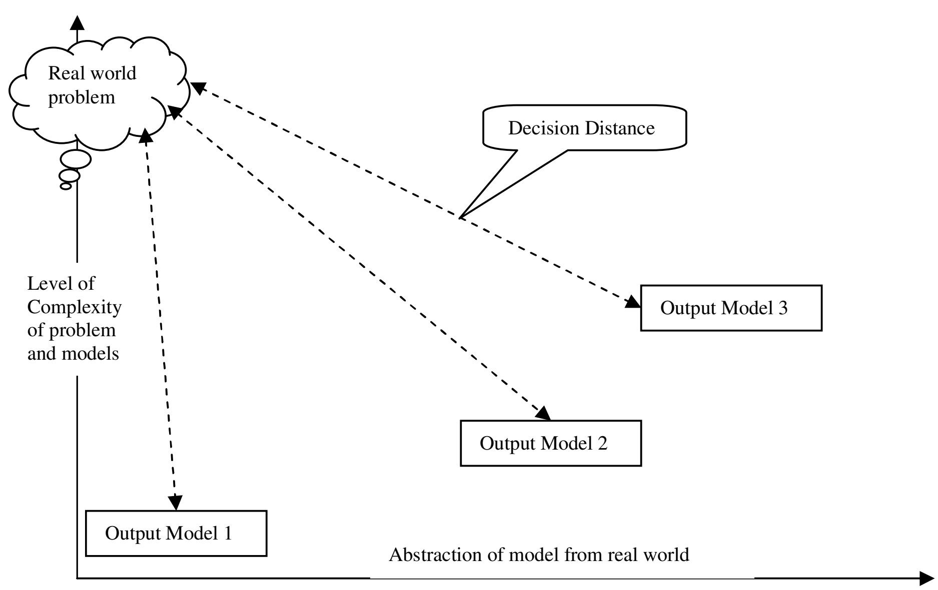

FIGURE 3
The Decision Distance

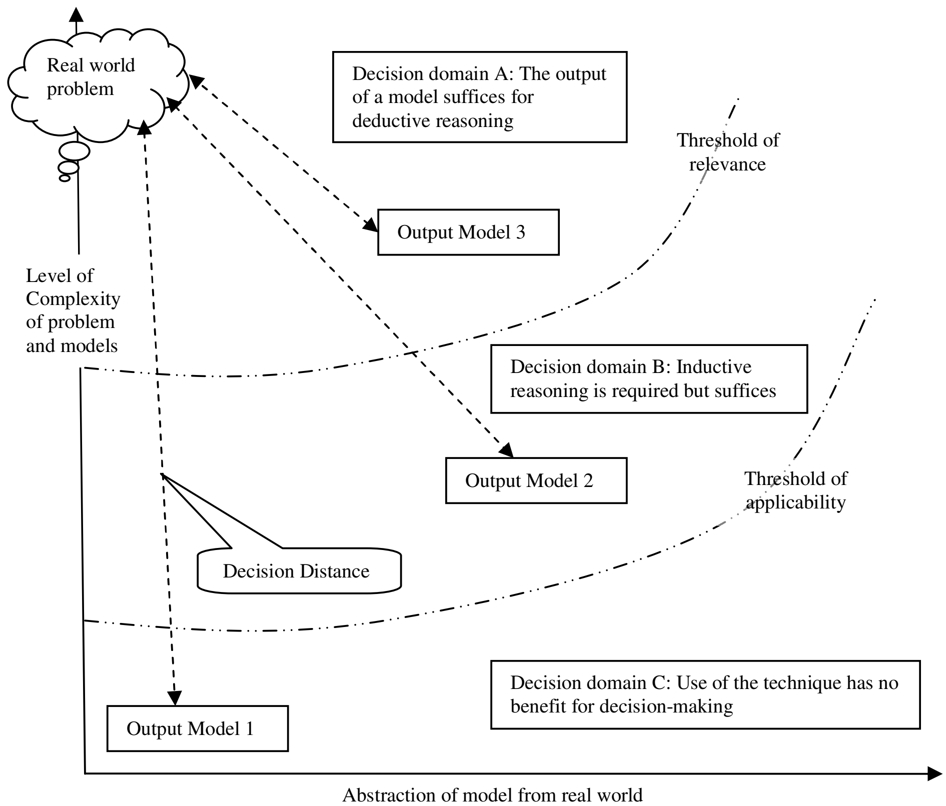

FIGURE 4
Decision distance across three domains