ADVANCING THE STATE OF THE ART IN THE MODELLING AND SIMULATION OF INFORMATION SYSTEMS EVALUATION

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Abstract

It is widely accepted that Information Systems Evaluation (ISE) is a powerful and useful technique that can be used to assess IT/IS investments in an a-priori *or* a-posteriori *sense. Traditional approaches to ISE have tended to centre upon financial and management accounting frameworks, seeking to reconcile tangible and intangible costs, benefits, risks and value factors. Such techniques, however, do not provide the IS researcher or practitioner with further insight or appreciation of any inherent and implicit inter-relationships, in the investment justification process. Thus, this paper outlines and discusses via a taxonomy and resulting classification, alternative and complementary approaches that can be applied to ISE from the fields of Artificial Intelligence (AI), Operational Research (OR) and Management Science (MS). The paper subsequently concludes that such approaches can be potentially used by researchers and practitioners in the field, as a basis for carrying out further research in the field of applied ISE.*

Keywords: Information Systems Evaluation, Artificial Intelligence, Operational Research, Management Science, Taxonomy

1 INTRODUCTION

There are many interacting socio-technical dimensions within modern organizations, requiring decision makers to have the skills to evaluate the impact of technology, in relation to the introduction of IT/IS. It is well understood that in order to ensure “value for money” via the quantification of direct or indirect benefits from information technology, usually involves lengthy and complex processes of investigation and analysis, commonly known as Information Systems Evaluation, ISE (Farbey *et al.* (1993); Hochstrasser (1992); Irani *et al.*, 1999; Small and Chen, 1995). Typical evaluation techniques include those which are based upon econometric or purely financial-based techniques (Hochstrasser, 1992; Primrose, 1991) where project costs, benefits, risks, organizational goals and technical considerations are all seen to be normative inputs. However, there is scope for expanding research in information systems evaluation, going beyond these traditional approaches. In this respect, the author supports and upholds the view of George P.E. Box, who notably opined that “All models are wrong – but some models are useful” (Box, 1979): Box alluding to the fact that decision makers sometimes have to make decisions with incomplete information, which may be only explained by the *best available* models. If the boundaries of a model are known, then the resulting boundaries of any decisions and interpretations of that model can also be restricted and understood better. It is in this vein, that this article attempts to expand the gamut of availbale modelling techniques which hitherto have not been applied to the field of ISE, in order to provide further insights into the ISE process. Specifically, the paper attempts to discuss and present the application of seven approaches to aid in the ISE process in the guise of Artificial Intelligence (AI), Operational Research (OR) and Management Science (MS) techniques and tools.

2 TECHNIQUES FOR MODELLING ISE: A REVIEW OF EXTANT METHODS

Ultimately, the aim of any decision-making or knowledge intensive task is to make decisions that balance competing goals using both complete and incomplete information. The accuracy needed from derived models of the world, is dependent upon the way in which the model itself is used and interpreted. In such a way, models themselves tend to adapt to the models that they are based upon – the so-called exogenous / endogenous effect of the influence of a system on the individual, and of the individual on the system (Sorensen and Kakihara, 2002). Sterman (2000) as well as Box (1979), suggest that any model of the real world should yield a fundamental kernel of knowledge at its core, about the context within which it exists. But at the same time, this model should allow us to understand its imperfections and the limitations of the world it is trying to represent, through the inclusion of human, social, systemic and process flows and other impinging factors. A natural consequence of this approach, means that if better, detailed or more complex representations of reality are defined, the accuracy of our predictions and quality of decisions should also increase. Thus, there is likewise need for better in-depth knowledge in IT/IS justification to make informed decisions. Any technique which can help the MIS researcher as well as practitioner, uncover and relate tangible and intangible factors should be judged on its merits (regardless of whether or not an ISE panacea is achievable or not). The author wishes to outline these complementary techniques available in this regard, by presenting a taxonomy of these relevant techniques, which are now briefly discussed in the following sections.

2.1 AI Techniques

2.1.1 Fuzzy Cognitive Mapping

The technique of Fuzzy Cognitive Mapping (FCM), based upon the concept of cognitive mapping (Montezemi and Conrath, 1986) and seeks to graphically represent state variables within a dynamical system, by links that signify cause and effect relationships, augmented with fuzzy or multivalent weights, quantified via numbers, or words (Kosko, 1991). Visually, an FCM is essentially a non-hierarchic digraph from which changes to each statement, hence fuzzy concept (i.e. node), are governed by a series of causal increases or decreases in fuzzy weight values (i.e. links between nodes). Whilst this representation provides a useful insight into the connectivities between each system concept, the power of this mapping approach comes into play, through the application of an iterative algorithm that proceeds to evaluate the interaction between each causal node (Aguilar, 2005; Grant and Osei-Bryson (2005); Khan *et al.* (1999) and Stylios *et al*. (1997). FCMs are useful in investigating and highlighting those factors within ISE as they allow experts as well non-experts in the field to quickly model and interrelate key decision factors, providing relational mappings between each of them, as shown by Sharif and Irani (1999), Irani *et al.* (2001) and Sharif and Irani (2006a). By analysing each of the inter-relationships, patterns of interdependent behaviour between each concept can be observed to emerge, highlighting the dynamics of such systems. A possible extension to the application of FCMs to ISE, would be therefore to not only model a given ISE scenario within an organisation but also to model multiple scenarios across the firm using a variety of such mappings.

2.1.2 Genetic Algorithms (GA)

Genetic Algorithms (GA) are a class of computational evolutionary system, which seek to mimic the behaviour of biologically adaptive systems (Michaeliwicz, 1996). These techniques encode specific design problem parameters into a population of bit string structures (chromosomes) and by using Darwinian principles of survival of the fittest, evolve each individual within the population via genetic operators such as reproduction, crossover and mutation from one generation to the next (Holland, 1992). Each evolved individual is evaluated in terms of its performance (the fitness), and those individuals which meet the constraints of an objective function (i.e. a prescribed goal state), survive into the next generation. The main aim of such procedures is to search for attractive or interesting solutions to large scale and complex problems via an optimisation of problem parameters, which have a large search space. Therefore, GAs are a useful optimization tool which can be used in a number of ways within the context of ISE. For example, a GA could be used to optimise those critical success factors involved (as shown in the development and optimization of a functional equation for costs, benefits, risks and value in Sharif and Irani, 1999); or could be used for optimizing a particular goal state for an FCM of ISE factors to converge to (as in the case of defining policy and goal decision states of an FCM, in Khan *et al.*, 1999). In addition, a GA could be used as a tool to select and refine those decision criteria that adhere to a given maximisation or minimisation critera: such as benefits for the former, and costs for the latter.

2.2 OR Techniques

2.2.1 Analytical Hierarchy Process (AHP)

The AHP procedure is now a well known technique for providing a systematic ranking of problem or system components, in a hierarchical and ordered fashion. This is achieved by defining a system in terms of known constituent components, and thenceforth applying a series of pairwise comparisons between each factor using a ranked scale (Saaty, 1986). This ranking of each component within the system being looked at allows decision-makers to make deductive and reasoned comparisons between many (and often conflicting) aspects of a given scenario. This is achieved by evaluating and thus producing a hierarchy of ranked and weighted factors (effectively highlighting which system components dominate others). As Suh *et al.* (1992) have shown, such techniques are amenable to a wide variety of organisational and non-organisational decision-making problems, where a large number of interacting and non-interacting variables is prevalent. Specifically they show the application of AHP in comparing and evaluating components of an IS implementation, basing their analysis upon components of a given IT/IS vendor solution. The application of this method in the wider sense of IS evaluation could therefore be in an *a-priori* sense, helping the MIS researcher or practitioner to identify those dominant criteria which might be observed to be driving the evaluation. Furthermore, beyond the identification of such criteria the AHP method could of course be used as a useful tool to help identify an appropriate evaluation methodology itself.

2.2.2 Monte Carlo Simulation (MCS)

Monte Carlo Simulation (MCS) has become a popular and powerful simulation modelling tool, over the last 60 years (Metropolis and Ulam, 1949). The basis of MCS essentially focusses on the modelling of the interplay between components of a system which exhibit random behaviour. As such, the naming of this method arose from an impetus to attempt to model games of chance typically found within the casinos of Monte Carlo (such games exhibiting notable random and unpredictable behaviour). The methodology used in this respect consists of identifying a parametric model of the system being studied, and thenceforth defining a statistical distribution of how each parameter within that model might behave (i.e. a strong assumption of the resulting output of the system). Hence for each variable within the given defined system, or at least for a variable which might have a wide range of unknown values, a probability distribution is applied – in effect, randomisation of the system parameters is carried out (Fishman, 1997).. The actual simulation itself is then executed by calculating multiple scenarios of the given parametric model, by repeatedly sampling the probability distribution for each variable in the system (known as “trials”). For each trial, statistical variances are calculated such as histograms, cumulative, mean, median, standard deviations and the like. By observing such data, it is then possible to deduce emergent characteristics of the system through the stochastically derived parametric model, thereby providing a near-real world representation of the system being studied. Given the right parameters and functional model of a system, it is possible to predict a output response from behavioural responses, historically. It is for this reason that MCS has been widely and keenly adopted across many fields and applications, such as for assessing financial risk (Bressman *et al.*, 1978), capital investments (Diguilio and Oakford, 1978) and more specifically IT investments (Svarvarsson, 2004). As far as the potential application towards ISE is concerned, a key factor in its application would be to define a model which would describe the main constituents of a given ISE process. Only after defining this model, could the parametrisation and definition of a probability distribution be applied in order to simulate the task of an ISE process. As has been showed in the literature on MCS however, a significant amount of time would be required in order to produce an accurate and representative sample population to be analysed, and an optimal and effective method of random number generation in order to carry out the simulation. As such, the use of MCS for ISE, would be to provide an indication of an evolving that is subject to the stochastic behaviour of the parameters which define it.

2.2.3 Game Theory (GT)

The basis of game theory resides in the requirement to model the range of decisions available to decision makers within a given decision-making scenario, who have certain preferences on the outcome of the decision (Morgernstern and Von Neumann 1944; Nash, 1951). In order to represent the game, strategies, payoffs, and outcomes are described in terms of a payoff matrix. This matrix, ultimately defines all the possible outcomes of each participant in the game, under certain (symmetric) or uncertain (asymmetric) information. And it is this matrix, which effectively is the game which is observed. By defining each of the factors which make up a game, a simulation model is in effect, produced. Any given uncertainties about the knowledge or the outcome of the game, can be further represented by assigning payoffs, which can be maximised in order to satisfy each participants preferences. The system which is thus defined, assumes that all the information necessary to describe the decision making situation is available, and that each of the participants in the game, exist to satisfy their preferences (their goals). The application of game theory has been successfully applied in fields as diverse as political negotiations, trade agreements, financial arbitrage, management decision making and other econometric tasks which involves the contractual involvement of two or more parties (Biermann and Fernandez, 1993). However, in the field of IS, there has been little or no application of this approach. The only available literature which points to the effective use of the basic concepts of game theory as described above, primarily centre around IS outsourcing (Elitzur and Wensley, 1997) and more predominantly, strategies for technology adoption (Zhu and Weyant, 2003). In each of these cases, the approach is mainly to map and define key stakeholders involved in the decision making task at hand, and suggest specific payoff functions, using strategies based upon common knowledge. Hence, the same approach would have to be applied to the case of ISE: the researcher would have to be able to define the given strategies and economics of the process in terms of the utilities of success / failure. As such, it is interesting to note how ISE could be modelled by GT – as a pareto or as an equilibrium-seeking system (i.e. a game of negotiation, coercion or conflict). For example, ISE could be modelled as a game of coercion, where the participants would be stakeholders in the organisation.

2.3 MS techniques

2.3.1 Systems Dynamics (SD) / Systems Archetypes (SA)

Systems Dynamics (or Systems Thinking as it is otherwise known) has existed in the academic as well as industrial R&D community for over 25 years (Ackoff, 1974; Forrester, 1961; Sterman, 2000), and has grown to become a useful modelling technique which employs variations on flow charting and state transition and dependency diagrams. Ultimately, Systems Dynamics (SD) is the basis for many other simulation modelling approaches, but essentially involves the identification of a problem domain or system, and the development of a simulation model which represents the behaviour of the system in the real-world. System Archetypes in particular, allow the modelling of a systems behaviours and outcomes in terms of 'rich picture' feedback loops and pre-conditions (Senge *et al.*, 1994). At the heart of the archetype view of the world, lie the concepts of the definition of a system's structure, the pattern of its behaviour and subsequently an explanation of the events which drive the system's behaviour. There are characteristically ten archetypes which define most type of social, organisational, political, economic or other (semi-) structured system: Limits to Growth/Success (i.e. finite reousrces and growth); Shifting the Burden (i.e. the application of "quick fixes"); Eroding Goals (i.e. degrading performance); Escalation (i.e. competitive monopolisation); Success to the Succesful (i.e. reward winners and their competency); Tragedy of the Commons (i.e. competition for consumption of resources); Fixes that Fail (i.e. negative feedback / worsening problems); Growth and Underinvestment (i.e. investment in resources); Accidental Adversaries (i.e. shared escalation); and Attractiveness Principle (i.e. which problem to address first). As such, ISE scenarios and experiences could be retrospectively modelled along the lines of any of these given patterns (specifically, ISE could be modelled along the lines of Fixes that Fail, Eroding Goals, Growth and Underinvestment; or even as Accidental adversaries, tragedy of the commons or accidental adversaries – all of which imply external factors beyond the control of the stakeholders involved in ISE.

2.3.2 Morphological Analysis (MA)

Morphological Analysis (MA) is a problem-solving technique, which seeks to quantify a systems' known parameters by reducing the solution space of the combined outcomes of all possible combinations of parameters which define a given system (Zwicky, 1969). Such a technique has been found to be useful in scenario planning, strategy formulation and forecasting in the fields of defence studies, economics and policy development (Coyle *et al.*, 1994; Ritchey, 1997). As such, the MA approach is used to define a structure of form (hence a morphology) of the system being analysed, so that it may be solvable. The MA technique consists of defining all the variables of the system to be modelled (i.e. the morphological dimensions), and then listing all the known outcomes or conditions for each variable – hence creating a morphological field, or matrix of the state of all conditions in the system. All potential known outcomes and responses for the system or problem being modelled should therefore, theoretically, fall within this matrix, i.e. these are the number of configurations (for which the product of n parameters by n conditions will exist). By filtering out those conditions which are vague, ill-defined or contradictory to each other, a reduced set of parameters is produced. A number of different "what if?" scenarios can then be played out by then defining a number of fixed conditions under a known parameter. By carrying out a walkthrough of all other known parameters and simplifying all known anomalies within the morphological field (by "relaxing" all the given anomalies in the field, Rhynne, 1995), a series of parameter configurations can then be explored. MA is a very powerful technique to produce a "universe" of known options which can then be investigated in isolation to each other; allowing for the expansion and contraction of all possible system outcomes. However, a key limitation in the case of ISE would be to acknowledge where and what such factors could be.

3 EXTENDING THE BOUNDARIES OF ISE MODELLING: FUTURE RESEARCH APPROACHES

<table>
<tr><th>Application / Form</th><th>A-priori ISE</th><th>A-posteriori ISE</th><th>Equivalent ISE method</th></tr>
<tr><td rowspan="2">Cognitive</td><td colspan="2"><u>FCM</u>
(Kosko, 1991)</td><td rowspan="3">CBA</td></tr>
<tr><td colspan="2" rowspan="2"><u>SDSA</u>
(Forrester, 1961; Senge et al., 1994; Sterman, 2000)</td></tr>
<tr><td rowspan="2">Systematic</td></tr>
<tr><td colspan="2"><u>AHP</u>
(Saaty, 1980)</td><td>ROI, IRR</td></tr>
<tr><td rowspan="3">Non-deterministic</td><td><u>MA</u>
(Ritchey, 1997; Zwicky, 1969)</td><td></td><td rowspan="4">EVM</td></tr>
<tr><td></td><td><u>GT</u>
(Bierman and Fernandez, 1993; Von Neuman and Morgenstern, 1953)</td></tr>
<tr><td colspan="2" rowspan="2"><u>GA</u>
(Holland, 1992; Michaeliwicz, 1992)</td></tr>
<tr><td rowspan="2">Stochastic</td></tr>
<tr><td><u>MCS</u>
(Fishman, 1997; Metropolis and Ulam, 1949)</td><td></td><td>NPV</td></tr>
</table>

Table 1. Classification of AI, OR and MS techniques for ISE

Table 1 shows where each technique can be used in relation to *a-priori* or *a-posteriori* ISE: the former in the sense of allowing the research to identify factors to be used within the ISE decision-making process; and the latter in terms of the ability to predict and interpret decisions, after the ISE process has taken place occurred. Each of the investigated approaches has been categorised in terms of four key forms of modelling approach: Cognitive (based upon mental or conceptual models of the process and / organisational inter-relationships); Systematic (based upon an explicit representation of knowledge using measureable data and information); Non-Deterministic (using techniques which do not assume or require convergence to a pre-defined goal state); Stochastic (based upon variations of statistically distributed, random variables and their associated outcomes relative to historical behaviour).

Likewise these forms have also been compared, albeit loosely, to traditional methods of investment appraisal in the table: Cost Benefit Analysis (CBA), Return on Investment (ROI), Internal Rate of Return (IRR), Earned Value Management (EVM) and Net Present Value (NPV). The latter categorisation has been carried out based upon the work of (Irani *et al.*, 2005, Sharif *et al.*, 2005, Sharif and Irani, 2006b), where it has been found that such traditional apprisal techniques are open and susceptible to explicit and implicit (tacit) views and behaviours of those carrying out the evaluation. As can be seen from this table, four of the approaches listed appear to useful in both *a-priori* as well as an *a-posteriori* sense. That is to say, the given techniques (FCM, SD, AHP, GA) are useful in not only identifying those drivers which need to be included in the appriasal of IT/IS, but are also useful in analysing the outcome of an evaluation scenario, in a post-hoc sense. Both MA and MCS methods are generally more applicable to providing an indication of a pattern which defines the evaluation scenario. On the other hand, the use of GT is largely theoretical (so far), in the sense of attempting to relate the known strategy of an evaluation, in order to achieve a desired outcome. Thus, the given methods can be broadly categorised into Behavioural (Cognitive and Non-deterministic) and non-Behavioural (systematic and stochastic) approaches. The former being applicable to ISE scenarios where there is a lack of knowledge or understanding of the ISE process; or where the number of required evaluation factors is uncertain. The latter categorisation on the other hand is applicable to those ISE scenarios where those involved in the investment apprisal have some experience of carrying out evaluations and / or where determinants of success and failure are suitably known.

Certainly, expanding the application of FCMs further in order to validate and verify existing ISE findings is a useful and apparent avenue of further research. Systems Dynamics / Archetype models can also assist in correlating those cognitive views which might be held by ISE stakeholders. Clearly the use and application of strong sociological, psychological and behavioural methodologies would underpin such an approach. Alternatively, genetic algorithms, morphological analysis and the use of the Monte Carlo technique, could be used to optimise and search for those factors which fit a particualr parametrisation of an ISE objective (minimise cost, maximise value for example). Finally, the use of game theory models could be used to understand those determinants of symmetric and asymmetric payoffs (i.e. utillities), of an ISE viewpoint. Noting these avenues of further research, it is still useful and important to realise that such evaluations to be carried out within a firm, are still reliant and are influenced by factors such as expert knowledge of ISE methods themselves (most applicable type of evaluation and context of evaluation (Ford and Sterman, 1998); socio-technical issues such as organisational culture, working practices and systems, which may interfere with the overall ISE process; and finally uniqueness (no two evaluations are the same as organisational, systems and stakeholders all influence and modify the behaviour of the evaluation process – as discussed by Irani *et al.*, 2005).

4 SUMMARY AND CONCLUSIONS

This paper has presented a brief overview of pertinent and useful techniques and technologies which could be applied to ISE: AI (FCM, GA); OR (AHP, MCS, GT); MS (MA, SDSA). These techniques were defined via a taxonomy which further led to a categorisation along cognitive, non-deterministic, stochastic and systematic lines respectively. As such, it was proposed that the resulting techniques within each topical area could be categorised between Behavioural (Cognitive and Non-deterministic) and Non-behavioural (Systematic and Stochastic) methods, where the former is based upon largely qualitative information and the latter upon quantifiable information. In doing so, highlighting the importance of distinguishing between tangible and intangible decision-making components to be modelled and analysed. The paper concluded by noting the contingent difficulties faced by ISE researchers in terms of influencing factors of expert knowledge methodology and domain knowledge, as socio-technical milieu of the evaluation process. Hence, even with the application of alternative techniques for modelling and simulating the ISE process, the author hopes that this article may be a useful reference for investigating further research avenues for both researchers and practitioners in this area.

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