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Systems modelling, simulation, and the dynamics of strategy

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Abstract

The paper presents, for consideration, the tools of systems thinking and simulation as a framework for managing the complex and dynamic process of strategy formulation, evaluation, and implementation. It addresses the question of how strategic thinkers can experience the paradigmatic shifts required to survive and prosper in the face of unremitting change, competition, and environmental turbulence. In response to this question, the paper argues that managers need to develop and cultivate a capacity to perceive and analyse relationships between their organisations and the business environment as a complex, adaptive, dynamic system containing nonlinearities, inertia, delays, and networked feedback loops. Principles of, and linkages between, systems and control theory, complexity concepts, business process orientation and simulation are explored, through discourse, within this context. The need to integrate fully operations management within the strategy development process is also emphasised. This leads to the presentation of an illustrative generic model of a marketing, production, and selling causal loop. Influence diagrams and dynamic modelling concepts are then applied to implement this representation and explore its dynamic behaviour using computer-based simulation and experimentalism as a research method. The results demonstrate how, even in a relatively simple case, nonlinearity can produce very different system behaviours depending only on minor changes in operational circumstances. The potentially counterintuitive behaviour of complex managerial systems and the implications for the strategy-making process are thereby highlighted.

Keywords: Modelling strategy; Simulation; Operations management

1. Introduction

Managers face an unremitting challenge to their capabilities in both the volume and complexity of factors to be reconciled. Rapid rates of change in the business environment are coupled with unprecedentedly fierce competition and the 'deification' of the customer. Additionally, in the search for optimal trade-offs between resource utilisation and customer service fulfilment, conscientious managers are faced with the potentially contradictory task of simultaneously upholding the interests of 'supply-side' product and service providers; their colleagues, team members, and employees. This can impose what often appear to be conflicting, if not impossible demands on those who seek to introduce and sustain organisational effectiveness.

In order to address these issues, managers, especially those operating at a strategic level, need appropriate tools to develop the thinking and learning paradigms that enable attainment of a more holistic and dynamic perspective. The role of organisational learning (OL) (de Geus, 1988; Argyris, 1990; Senge, 1990) and knowledge management (Hall, 1992; Boisot, 1995; Nonaka and Takeuchi, 1995; Davenport and Prusak, 1998) have been quite rightly associated with these requirements. Similarly, the importance of business process as a continuum of seamless, cross-functional activity integration, is now seen as a vital prerequisite of organisational success (Hammer, 1990; Hammer and Champy, 1993; Wolstenholme and Stevenson, 1994; Youssef, 1998). However, in order to assist managers to harness these theories and implement their objectives appropriate models and analytical frameworks are required, which accommodate the full dynamic complexity and uncertainty, which characterise contemporary strategic management.

This paper argues that the theories of 'systems thinking' and 'complexity' can potentially provide such frameworks. Furthermore, the supporting 'toolbox' of continuous system and hybrid (continuous and discrete) simulation potentially provides an excellent medium for

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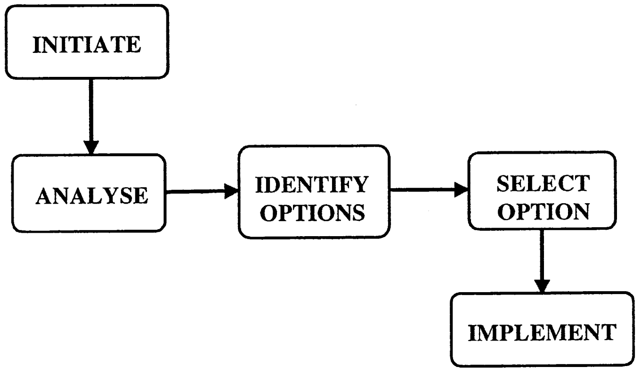

Fig. 1. Linear strategic action sequence.

enacting and exploring the dynamic nature and complex behaviour that characterise the phases of strategic analysis, development, and implementation, respectively.

2. Design vs. emergence

A characteristic of the uncertainty surrounding the concept of strategic management is the absence of agreement on a clear, unambiguous, and reliable model of the strategic process itself. This is epitomised by the running debate between what has come to be known as the 'design' or prescriptive school of thought vs. the 'emergent' or crafting school (Mintzberg, 1990; Ansoff, 1991; Lynch, 1997).

In its simplest form, the prescriptive model may be seen as a linear, sequential process as identified in Fig. 1. However, most contemporary thinking would probably accept that a more representative view would be inherently more systemic with blurred cause and effect linkages and sequences of action that are iterative, dynamic, and nonlinear. Hence, top–down, prescriptive models have been challenged by, for example, Mintzberg (1987) who succinctly notes:

> The popular view sees the strategist as a planner or as a visionary; someone sitting on a pedestal dictating brilliant strategies for everyone else to implement. While recognising the importance of thinking ahead and especially of the need for creative vision in this pedantic world, I wish to propose an additional view of the strategist as a pattern recogniser; a learner if you will, who manages a process in which strategies (and visions) can emerge as well as be deliberately conceived.

Hence, according to the crafting school, the full strategy will not be known in advance but will only emerge during actual implementation (Mintzberg and Waters, 1985).

Also central to the philosophy underpinning the emergent approach is the role of OL that seeks to accommodate the true complexity characterising the relationship between the organisation and its environment (de Geus, 1988). This may be seen as an extension of the flexibility concept, inherent in the crafting perspective, and becomes increasingly important when 'quantum-leaps' or large step changes are encountered (usually resulting from changes in the external environment or dramatic internal responses aimed at rectifying long-term strategic drift). Systems thinking, as a viable method for surfacing, analysing, and understanding the dynamics of strategy and organisation, is implicit within the OL paradigm (Senge, 1990; Richardson, 1991; Morecroft and Sterman, 1992; Richmond, 1994).

More recently, additional insights into the complex dynamic processes, which characterise strategic management, have been provided by the complexity theorists (Kauffman, 1993; Stacey, 1996); an issue that is also addressed, in summary, in the following section.

3. Dynamics, control, and complexity in management systems

Strategic planning and control are often envisioned, within the framework of the 'stable equilibrium' paradigm (Stacey, 1995). This implies the setting of some target objectives linked to the mission statement, typically following the prescriptive approach outlined above. This is followed by monitoring of actual performance or outcomes for comparative purposes. Combinations of feedback and feedforward control (Fowler, 1999) are then implemented with the intention of ensuring that the actual system performance tracks the target requirements, over time.

Typical examples of such feedback loops are evident at the 'macrolevel' in Fig. 2 that shows, respectively, the stages of discovery (analysis), choice (evaluation and selection), and action (implementation). Control then comprises the linking of the implementation and analysis stages to form, in effect, a closed-loop feedback mechanism comprising performance monitoring, comparison with targets, and subsequent action to ensure convergence. This process may be seen as analogous to single loop learning, as defined by Argyris and Schon (1978).

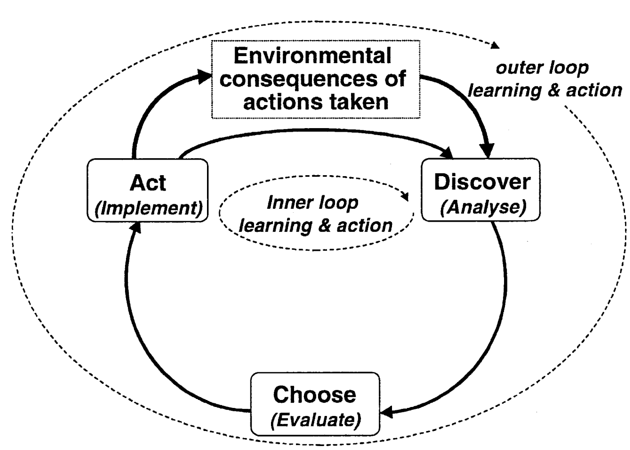

Fig. 2. Looped strategic action sequence.

Extension of this representation into a form of double loop learning is also evident in Fig. 2. The external loop acknowledges the consequences of internal actions, with respect to their impact on the business environment (e.g., competitors, buyers, or suppliers). Hence, choice of strategic options may now be further modified through changes in the target settings applied to the inner control loop.

If this perspective is applied to a system (organisation) assumed to be operating in the 'stable equilibrium' paradigm, then although the existence of change is securely acknowledged, primary attention focuses on the attained, final conditions of dynamic equilibrium, or 'steady-state'. This tacitly implies that interim transient states are of limited consequence and assumes that the system is always drawn, partially as a response to managerial actions, towards some equilibrium condition with behaviour patterns that are orderly, regular, and consensual (Stacey, 1995, p. 100). Systems of this type may be characterised as possessing stable attractors or 'equilibrium magnets' towards which behaviour is inevitably drawn.

However, there are dangers inherent within this paradigm. For example, systems design in the very physical world of engineering, shows many cases of critical failure arising during the statistically unlikely, but distinctly possible, transient regimes encountered in systems that have been designed primarily for steady-state operation (Fowler and Orbeck, 1986). Similarly in organisational life, the transition between two apparently feasible end-states may prove 'unnavigable' in practice with the result that failure transpires before the equilibrium condition is attained. Such is the potential trajectory of, for example, many BPR projects.

3.1. The contribution of the complexity theorists

Colloquially, complexity is often regarded as the property of a system, which has many parts, intricately connected together; such as occurs in a complex machine. However, complexity arises not merely because of the number of parts; it also arises as a consequence of the nondeterministic and nonlinear characteristics of the component parts and from the nature and structure of the interconnections between them.

Stacey (1996, p. 10) offers the following definition of complexity that finds resonance within the domain of organisational dynamics and strategy introduced above:

> The science of complexity studies the fundamental properties of non-linear-feedback networks and particularly of complex adaptive networks. Complex adaptive systems consist of a number of components, or agents, that interact with each other according to a set of rules that require them to examine and respond to each other's behaviour in order to improve their behaviour and thus the behaviour of the system they comprise. In other words, such systems operate in a manner that constitutes learning. Because those learning systems operate in environments that consist mainly of other learning systems, it follows that together they form a co-evolving suprasystem that, in a sense, creates and learns its way into the future.

3.2. Elements of complexity in systems

Feedback is the first core property of complex systems. If feedback loops occur within a system, so that inputs are no longer independent of outputs, then this immediately introduces the potential for much more complex modes of behaviour than would appear in an open-loop, linear, sequential system. Such feedback loops can occur naturally but are often created deliberately to form a negative configuration. In this case an output is fed back to activate a balancing or controlling mechanism, guiding the system towards some defined equilibrium condition. The effect is to negate any discrepancy between required and 'actually attained' performance. However, feedback can also be used in a positive configuration whereby outputs are added to inputs to create a multiplier effect. In this case, the influence is usually destabilising, leading to 'explosive behaviour' with outputs asymptoting towards infinity.

Dynamic systems are also characterised by delays or 'inertia', which, in the physical world, are often so small that they may appear nonperceptible to the human senses. However, in the particular case of management systems, such near instantaneous responses are rarely if ever present, as delays and inertia are usually considerable, sometimes being measured in years (Larsen and Lomi, 1996).

The concept of inertia implies the property of elements within the system to naturally maintain their current state over time. Hence, state can only be changed incrementally over a period of time, as a result of a net imbalance between the forces, or energy streams, acting on particular elements within the system. The 'exponential lag' type of response (the S curve), following the application of a step change in external influence typifies, such change.

In contrast, the affect of a pure delay is to produce a change in output, which reflects exactly, the change in input (i.e., a nongradual response) but displaced in time by some finite interval.

The combination of lags, delays, inertia, and feedback ensures that considerably complex dynamic behaviour can result, even in a deterministic system, especially during transient events when the system is disturbed from some equilibrium condition. Such circumstances are readily and perhaps most 'tangibly' evident in stock-control and supply chain management settings (Towill and Naim, 1993). In these cases, already complex subsystems (i.e., whole organisations) are cascaded together as a 'suprasystem', linked by information exchanges and material flow.

Perhaps less obviously, any process involving activities in which people are involved in learning, or the assimilation of 'intangible stocks' such as, for example, impressions, prejudices, reputations, or power, is also potentially subject to analogous dynamic behaviour (Kelly and Amburgey, 1991; Fowler, 1998). This can occur in any system in which there exists an information transfer linkage flowing from an output, back to the input side of the system.

The final factor which contributes to complexity is nonlinearity. The default conceptual model of most analysis tends to revert to the linear perception whereby outputs for a given process or subprocess are considered to be directly proportional to inputs. Although this is often a good approximation, as long as disturbances to the system are small, it is rarely true in absolute terms. Virtually all 'real-world' system elements are nonlinear in practice and many are, in addition, highly stochastic. As a result, behaviour initiated by stark disturbances to the system, such as occur in BPR for example, can be highly counterintuitive and virtually unpredictable by conventional cognitive mechanisms (Sterman, 1989).

3.3. What is new in complexity theory?

The converse of the stable, equilibrium (Type 1) attractor, such as that existing in the negative feedback controlling loop, as typified by deployment in the traditional planning and control cycle, is the unstable (Type 2) attractor. This is characterised by the behaviour of positive feedback loops in which the system tends towards some extreme position, diverging sharply from any stable equilibrium condition until eventually being arrested by some external limit. Perhaps, somewhat paradoxically, positive feedback is, in systems terminology, usually perceived as undesirable as it inherently implies uncontrollability and an inclination towards instability.

A third form of attractor, which may be considered stable, in the sense that it is confined and repeatable, is the steady oscillation or limit cycle (the Type 3 attractor). This can appear in negative feedback systems that are operating at the limit of stability where sensitivity or 'system gain' is too high to allow steady equilibrium to develop (due to continuous overshooting) but not high enough to promote continuous growth towards the truly unstable condition associated with positive feedback.

Notably all three of the above attractors are potentially evident in linear dynamic systems and have been studied extensively for several decades across a range of disciplines including biology, physics, economics, and engineering (Ashby, 1956; Beer, 1959; Forrester, 1961). However, the addition of nonlinearity can, under certain conditions, give rise to the occurrence of a fourth category identified by complexity theorists as 'the strange attractor' (Type 4). In this case, the behaviour of the system can alternate between stable, negative feedback, and unstable positive feedback modes. Therefore, the output state is continuously changing but in a nonrepeatable and complex pattern as typified by the so-called butterfly effect (Lorenz, 1963). A characteristic of such systems is that small variations in initial conditions can produce massively disproportionate and unpredictable changes in output.

Advances in complexity theory are most prominent in the physical and biological sciences but its potential impact on social science generally, and management in particular, is an issue of widening debate. Indeed, it has been claimed that the science of complexity potentially makes a substantial contribution to the understanding of organisational phenomenon (Stacey, 1996, p. 263).

Hence, complexity theory shares, with other open systems theories, the notions of paradox and susceptibility to opposing forces such as differentiation and integration (Lawrence and Lorsch, 1967), formal and informal organisation (Trist and Bamforth, 1951), and sociotechnical systems (Miller and Rice, 1967). It also shares with the discipline of 'system dynamics', the study of nonlinear dynamic networks in which unclear and distant cause effect consequences often arise (Forrester, 1969; Senge, 1990). However, complexity theory diverges sharply from earlier concepts in that it focuses specifically on the behaviour of systems in the region at the boundary of stable equilibrium. In this vicinity, truly unpredictable behaviour emerges and the conventional management goal of control becomes futile and pointless.

However, this region can often contain the potential for spontaneous and creative organisation. For example, the tension arising due to the existence of 'the shadow system' (comprising the social and political interactions that lie beyond the prescribed 'legitimate system') can prove to be a vital factor in this potential creativity (Stacey, 1995). Hence, those who would seek to manage organisations at the 'edge of chaos' will require the means to ensure appropriate learning in order to recognise and create the conditions that engender such spontaneous self-organisation. Stacey sees this form of activity actually displacing more conventional managerial efforts, which traditionally seek to devise ever more complex systems of control.

4. The process perspective

Another major development in 'management thought' that occurred during the 1990s was the redirection of emphasis towards the analysis, design, and reengineering of business processes as epitomised by Hammer and Champy (1993). Therefore, the issue of process has now achieved equal status with strategy and organisation theory as a concern for debate and analysis at the highest level within organisations.

A further manifestation of the business process emphasis is that in raising this issue to the strategic level, the role of operations management, is also brought sharply into focus. Arguably, one of the side effects of the predominance of the design-school approach to strategic management, with its emphasis on top–down planning and hierarchy of actions, is the emergence of a relatively negative view of the role of operations (Hayes and Wheelwright, 1984). Hence, although often containing the bulk of the firms resources operations has too often come to be seen as a somewhat troublesome functional entity manifesting only in the tail of the strategic planning process and somewhat remote from the mainstream strategic process.

However, such a view would, presumably, be totally unacceptable to the proponents of emergent strategy or resource-based strategy models (Mintzberg et al., 1998; Hamel and Prahalad, 1994). This school has, in effect, consistently argued that strategy should be crafted and grown out from a carefully nurtured operations environment: operations being defined here in the broadest terms to include several functional segments in the value chain (Slack et al., 2000; Fowler, 1998).

The net impact of these developments is to potentially redefine perceptions of operations management. The transformation of input resources into higher value outputs, through appropriately designed, maintained, and improved business processes is, after all, the very essence of the discipline. Consequently, in a holistic and systemic perspective of strategic dynamics, it is clearly erroneous to delegate operations to the status of an afterthought. Rather it should, as the custodian of the value adding process, be promoted into a much more central role as a potentially rich source of understanding and creativity within the dynamic, systemic paradigm of strategic thinking.

Hence, contemporary approaches to designing and redesigning (reengineering) business processes increasingly recognise the need to create a better-integrated, more holistic vision of the organisation. This must focus on effectiveness derived from superior management of linked activities, which cut across the traditional functions; ultimately linking customer demands (the primary input) with customer satisfaction (the ultimate process output). In this sense, many of the major ‘paradigms’, such as TQM, JIT, BPR, concurrent engineering, and supply chain management, appear to share much in common.

The problem is that such holism and breadth of vision do not come easily. Hence, in practice, reductionism and functionalism (defined here as accommodating organisational complexity by reducing the whole into discrete, functional segments) have provided the traditional and long-standing approach to the problem of efficiently subdividing work. In practice, the limitations associated with the need to harness a wide diversity of specialist knowledge and skills may, to many, appear optimally accommodated by such functional structuring. Hence, many would argue that the ‘Tayloristic’, functionalist paradigm has been particularly successful during the 20th century at delivering an unprecedented volume of industrially generated wealth.

In contrast, as technologies and expectations change, many would argue that the advantages of such functional approaches are more than outweighed by the disadvantages. In particular, departmental rivalries and interfacial disfunctionalsim seem inevitably to arise. In this sense, it is evident that the functionalist perspective too easily allows local contributors to lose sight of overall organisational goals. Hence, when viewed from the systemic perspective, the increasing entropy associated with functional structures and activities ultimately leads to stagnation and decline.

Conversely, switching the emphasis onto process management and a more holistic perspective impels focused reevaluation of the total value-adding mechanism. However, in making this transition the analyst is inevitably brought face to face with the full and unabridged complexity of organisational life, including phenomena of the type highlighted in the preceding sections. This introduces the need to promote deeper insights into the dynamic working of the total system that, in turn, promotes the need for what has come to be termed ‘organisational learning’.

5. OL through modelling and simulation

The importance of inducing the ability to think dynamically and holistically has been strongly emphasised in the preceding sections. However, in beseeching managers to acquire such holistic perspectives, the dynamic complexity of management systems must be confronted head-on. Any assumption that the effectiveness of the whole will be achieved automatically, as long as functional management of the parts is adequately addressed, can no longer be sustained within the systemic paradigm. The organisation and its strategies must now be viewed in their entirety, as must their dynamic interactions with the environment. Furthermore, the need to explicitly identify internal and external interfaces between functions, disciplines, and professional groupings, with a view to ‘dissolving’ impediments to process flows, must be treated as a top priority. Clearly, this requires a cross-disciplinary approach featuring clear communication linkages bearing in mind that different disciplines tend to speak ‘different languages’ (Richardson and Andersen, 1995). For example, accountants are well versed in the language of balance sheets, profit and loss statements, and cash flows. Likewise engineers communicate using the language of mathematics, blueprints and computer models while information systems professionals emphasise flowcharts, entity relationship diagrams, data dictionaries, etc. Even natural language, which should be a common denominator to all parties, has its semantic difficulties with local acronyms, technicalities, nuances, and value-laden connotations that are often specific to one particular group, profession, or ‘school of thought’.

Hence, a particular tool available for communicating, analysing data, modelling, and supporting complex decisions in one particular profession, will not necessarily be familiar to all members of a cross disciplinary team. For example, the classical tools of ‘operations research’ are often seen as being inaccessible, remote, and unrealistic to many practical managers, especially those lacking a rigorous mathematical background. Conversely, natural language, which is the most commonly used medium of analysis and communications, can too easily lead into entropic ambiguity, inflation, and diversion. Arguably, what is needed in many situations is a bridge to facilitate linkages between the 'hard and soft' ends of the systems spectrum.

Similarly, when mapping processes, structures, and activities that purport to represent the organisation and its environment, problems often arise in devising means whereby a realistic degree of complexity can be captured in dynamic models based on the shared experiences of all the key 'actors' involved in supporting the core business processes (Thompson and Weiner, 1996). The technique of 'brown-paper walling', often used in the BPR context to establish the nature of existing processes, is a useful start but does not, of itself, create a 'live model' that can subsequently become the subject of 'hands-on' experimentation. What is required at this stage is a facility to bridge the gap between the descriptive, iconic representation of process (typically depicted in the initial stage of such an analysis using 'Post-its' stuck onto a roll of brown paper) and the quantifiable data with which 'experiments' can be subsequently conducted and from which results can be collected and analysed. This is precisely where simulation can potentially deliver its maximum impact.

Hence, in recent years, the process of team-building and OL through modelling has been promoted by a number of writers (Senge, 1990, Morecroft and Sterman, 1992; Richardson and Andersen, 1995). The basic proposition is that a common, easy to learn modelling resource is made available, probably through the medium of a facilitator, to a group of managers who collectively share ownership of a complete business process. This medium is used to build models, developing through a step-by-step approach in which component parts of the organisation are systematically analysed in terms of inputs, processes, and connectivities. Examples of the 'systemic languages', which are typically used, include causal influence diagrams and iconic representation based on 'stocks and flows'. Both approaches are briefly presented below.

5.1. Influence diagrams

Typical examples of high-level influence diagrams have been presented by Senge (1990) as 'system archetypes'; typified by 'limits to growth' and 'the fix that fails'. At a lower level, such diagrams can be built up in stages incorporating lags, delays, and nonlinearities of the type discussed earlier. This can be achieved by encouraging managers to postulate the likely effects of certain actions or processes in terms of their causal effects on outcomes. Upon cascading these together and completing the sequence, processes inevitably aggregate into delayed closed loops of the kind described previously. By this means the existence of feedback, which on aggregation around the loop may be either positive (destabilising) or negative (balancing) may be recognised where previously it might not have been suspected. Furthermore, gaining an understanding of the implications potentially arising due to the existence of such closed loops can now be conceptualised through awareness of systems concepts. Overall, this process can be described and envisioned as 'qualitative modelling'.

5.2. Modelling with stocks and flows

An extension of the influence diagram approach involves the creation of subsystem models using 'stocks and flows' to represent, respectively, accumulations of certain entities or state variables (stocks) that are of primary interest, and the flows that create or deplete them. The most obvious and tangible examples of stocks are inventories of raw material, work in progress, and finished product. In this case, typical process flows include manufacturing (filling) and selling (depletion). However, it is also possible to postulate less tangible factors that are known to effect organisational effectiveness such as morale, productivity, reputation (real or imagined), and goodwill. All of these can be thought of as stocks that can gradually rise or fall, over time, depending on net flows that arise from within the organisation but also from outside. However, an important difference, in this case, is that there is no formal and quantitative means of measuring such entities; no universally accepted system of units or even agreed definition of terminology. Nonetheless, it would be naïve to simply ignore their existence. Consequently, some means has to be devised to incorporate such effects into our models even if this is less than perfect from a numerically scientific perspective. A simple example demonstrating the use of such a technique is presented later in this paper.

Upon building up the respective subsystems, based on managers' knowledge and understanding of their particular part of the system, it is eventually possible to complete the network by connecting the informational linkages that join the outputs from each subsystem to the inputs of all the others. In effect, organisational complexity can thereby be represented following a bottom-up process, which is inherently compatible with, and highly reminiscent of, the 'crafting school' of strategic thinking. However, this model can then, if so wished, be used at a strategic level in a top–down holistic manner to investigate the likelihood of various outcomes. Notably, in this sense, the approach is not necessarily incompatible with the design school of strategic thinking. This implies a high degree of flexibility.

5.3. Modelling, simulation, and the three phases of OL

A primary function of simulation is to contribute directly and powerfully to the OL process. Within this context, the process may be envisioned as three distinctive and sequential activities. First comes the qualitative stage of learning, which occurs amongst the participants through the medium of group discussion and analysis at the stage when the model is being formulated. Hence, the discipline of having to sit down with an often diverse group of cross-functional team members, with a mandate to think about business process management, within the structured framework of a systemic modelling language, can prove highly revealing, in its own right. Even before the final closing linkages between subsystems are completed, or any attempt is made to introduce quantification, participants can thereby experience deep insights into the working of, and interactions between, particular subprocesses. The influence diagram technique referred to above is a potentially excellent tool for facilitating such a process.

If a decision is taken to advance to the next stage, in which the model is used to dynamically explore alternative scenarios, a second stage of learning is then initiated. This occurs when the attempt is made at implanting the numerical data required to make that transition. At this stage a clear impression of relative weightings and the strength and nature of relationships is developed. Recognition of the existence of nonlinearity and the exercise of estimating the variability of parameters further sharpens perceptions of how the system works. Simulation based on stocks (dynamic state variables) and flows again provides a potentially excellent medium through which to proceed.

Finally, the third stage of learning occurs at the experimentation stage when the models are actually run and results analysed. The design of informative 'experiments' will reflect expectations of what externally imposed shocks to the system could be encountered. Similarly, impacts arising from proposed restructuring can be portrayed as dramatic disturbances to the system. Consideration of the likely response of the system, to such disturbances, fundamentally helps to develop and encapsulate awareness of interrelationships and dependencies. Furthermore, developing an ability to translate the graphical dynamic outputs of the model into an understanding of how the real system is likely to behave, potentially enhances understanding, reduces uncertainty, and further builds confidence. Hence, enablement, through experimentation, to explore the behaviour of the model, following changes in system parameters or reengineering initiatives, provides potentially invaluable learning experiences. These can subsequently help managers to deliver favourable results while avoiding potentially disastrous outcomes.

5.4. Simulation as an executive learning and decision support system

Clearly, the imaginative and disciplined application of dynamic modelling and simulation potentially provides a useful mechanism through which managers can gain a comprehensive understanding of system behaviour, concentrating on core business processes such as order fulfilment, product development, and customer acquisition, satisfaction, and retention (Fowler, 1998). However, the means by which management in general and senior management in particular make decisions can, in itself, also be regarded as a core value-adding process that impacts fundamentally upon the overall effectiveness of the organisation. Classically, the process starts with problem recognition and identification and proceeds through successive stages of information-gathering, sifting, analysis, decision-making, and implementation. Furthermore, in keeping with the concepts discussed earlier (design vs. emergence) this need not be a linear, open-ended sequence but may manifest as a closed-loop feedback system in the event that the decision outcome impacts, in time, on the original problem, or creates a new problem.

Hence, simulation can potentially play an important role as an executive decision support tool, acting as a medium through which each of the above stages can be enacted. Within this sequence, the simulation study may be combined with, or preceded by, a soft-systems analysis (Checkland, 1981) to clearly identify the nature of the problem. The qualitative phase of modelling may also prove helpful in this respect by finely tracking process mechanisms, thereby highlighting the origin and nature of problems. The information gathering, sifting, and selection phase is similarly guided and rationalised during the transaction from qualitative to quantitative modelling when hard, relevant data must be captured or postulated. The actual decision-making stage can now be performed within the framework of 'microworld' experimentation (Morecroft, 1992, 1999; Morecroft and Sterman, 1992; Kim, 1999) that allows the likely consequences of implementation to be viewed within a compressed timeframe. An iterative approach towards strategy development and organisational redesign can thereby be pursued until the process eventually converges on an outcome, which is considered optimal by the decision-making group.

6. A simple example of a typical nonlinear subsystem model

The application of influence diagramming and simulation is now presented in the form of a simple example using a model depicting some of the concepts discussed in the preceding sections. This serves to illustrate the way in which the combination of feedback loops, delays, and nonlinear system characteristics can produce totally different outcomes in a system's behaviour, depending on relatively small changes in operating conditions. The model essentially depicts the generic relationship between marketing, producing, and selling; all of which combine in a nonlinear closed loop implying mutual causality. Despite its simplicity, the model possesses dynamic capability since it contains inertia elements and delays. It also accommodates nonlinearities expressed in the compounding of the characteristics associated with its various elements. When represented in this form the existence and nature of feedback and feedforward information linkages is also clearly evident.

The key point is that the model possesses similar dynamic behavioural characteristics to the real system, subject only to the accuracy and detail associated with the perceptions and objectives of the managers who create it. In other words, it may be modified, augmented, or simplified at will according to the requirements of its originators and users.

The influence diagram representation, Fig. 3, indicates that initially, a nominal target is established for profitability, against which is compared the actual profitability arising from sales achieved. Upon detecting a gap between the target and achieved values, the organisation responds by increasing its advertising effort (in influence diagram terminology ‘S’ stands for ‘support change’ and ‘O’ stands for ‘oppose change’). This takes a while to take effect but the outcome eventually achieved is an increase in ‘goodwill’ followed after a short delay by an increase in sales, albeit in a nonlinear manner with diminishing returns as the saturation state is approached. This represents a classic, nonlinear, negative feedback loop with ‘goal-seeking’ behaviour (convergence of actual with target profitability, in this case).

Fig. 3 also shows the link representing the cost associated with the advertising campaign. This is assumed to rise nonlinearly with negligible delay thereby serving to reinforce the profitability gap (i.e., a positive feedback loop also exists).

The corresponding simulation ‘patch diagram’ model is presented in Fig. 4 Note the term ‘patch diagram’ is used since complex models can be assembled by patching together a number of standard components such as stocks (the rectangles), flows (double lines with attached circles), and converters (other circles) using connectors (arrowed, single lines). The model assumes gross revenue proportional to sales. Net revenue takes account of the cost of advertising and variations in marginal production costs, which are a nonlinear function of the sales achieved. This accommodates additional costs due to overtime working and similar factors associated with any surge in production required to satisfy additional sales. The achievement of sales is itself, subject to a delay, relative to the attainment of ‘goodwill’ from which it derives. Note also the use of a ‘soft-stock variable’ here to represent the amorphous quality that we have termed ‘goodwill’, as contrasted to the ‘hard-stock variable’ for profitability and sales (which can, of course, be

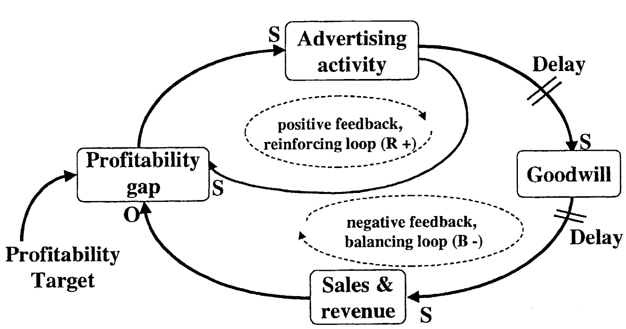

Fig. 3. Influence diagram.

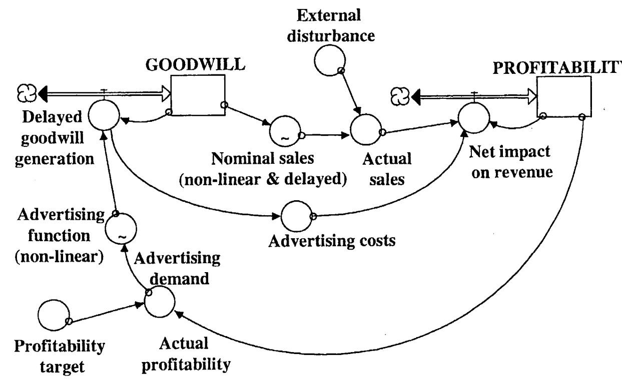

Fig. 4. Simulation patch diagram.

readily measured using real numerical units). Although goodwill cannot be measured and represented in fixed quantifiable units, it is nonetheless possible to postulate a nominal nondimensional quantity (say 50%), which is considered to be the norm, and then accommodate relative variations about this value (say in the range 0–100%).

The response of this simple model following a disturbance from the environment (depicted in Fig. 5 as a step increase in competitor activity that produces a corresponding decrease in actual sales) may now be investigated. During normal operation within the stable, equilibrium operating domain, the system is seen to remain robust to the effect of external disturbances such as the actions of competitors. Corrective action occurs through the advertising loop to maintain goodwill and profitability levels within acceptable limits as shown in the simulation response traces.

However, the same simulation model may also be used to show that a marginally larger disturbance (the situation depicted in the simulation trace, Fig. 6) produces a very different response. In this case the system is pushed up to, and beyond, the point of maximum return. Hereafter, further advertising increases costs disproportionately to sales. As a result, net profit begins to decline. The response is to increase advertising but from this point on the net effect is counterproductive. Goodwill increases but profitability

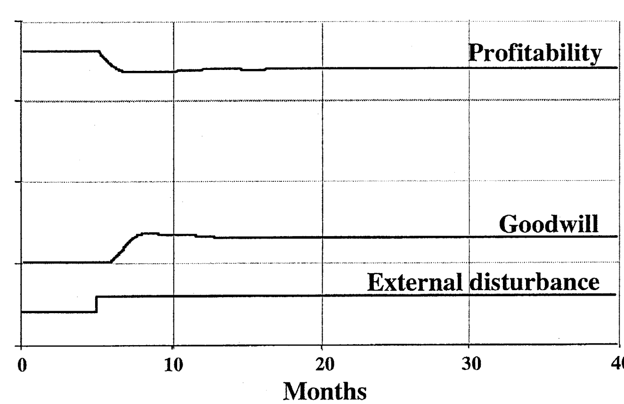

Fig. 5. Stable response.

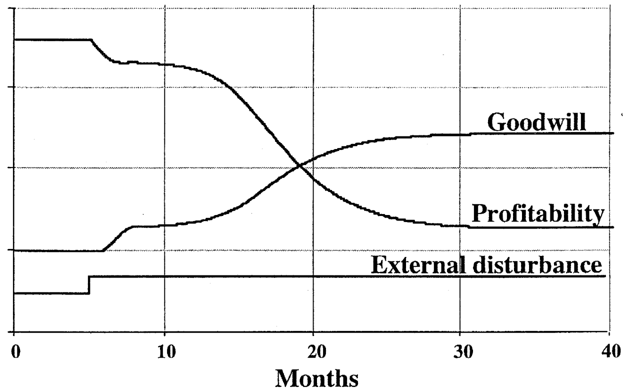

Fig. 6. Unstable response.

slumps. This occurs because, in effect, the system has been flipped from a stabilising negative feedback mode of operation into a destabilising positive feedback configuration, due to the action of its nonlinear characteristics. Hence, its behaviour changes spontaneously from a stable mode into an unstable one. The result, as depicted in the simulation trace, Fig. 6, is a compounded downward spiral towards collapse. In other words, the same system behaves completely differently depending on only an infinitesimal change in its operating regime. In this sense it is, in effect, operating at the limit of stability, at a point where the characteristics or behaviour of the system appear to change completely between one point in time and the next. Such transitions are typical of the behaviour manifested by complex systems.

This is a much simplified and fairly transparent example of the possible outcomes arising in nonlinear, dynamic feedback systems. However, it does provide a graphic example of the way in which the simulation approach can be used to capture and envisage strategic dynamics. This approach can be readily developed to express the characteristics of the more realistically configured complex system models, which arise in practice. This, in turn, can enable managers to understand the potentially explosive and unexpected behavioural consequences that arise, purely due to the dynamic structure of the systems that they are working with.

The simple model presented above is readily extensible and could, in practice, appear merely as a subsystem within a more complex suprasystem involving many other functional departments, collectively participating in core business process analysis. Naïve assumptions revealed in earlier versions of the model can then be successively relaxed as the modelling and experimentation process proceeds through various iterative evolutions until the requisite level of complexity is accommodated. Within such a setting, access to tools such as dynamic simulation can prove invaluable, as it is notoriously difficult to predict the behaviour of even relatively simple, nonlinear dynamic systems, without some form of mental aid. The presentation of future predicted scenarios can thereby provide a degree of foresight rather than having to wait and see how the real system actually behaves.

7. Conclusions

Although acquired experience and inherent managerial ability may engender impressive capabilities attributing to individual managers, there remains a limit to the extent to which the unassisted human mind can simultaneously retain and process the full dynamic complexity associated with the wide-ranging and far-reaching strategic change management scenarios featuring in contemporary organisational life. Furthermore, the difficulties experienced are potentially magnified in scale and multiplied in number when large, step change initiatives are encountered, such as occur in BPR or supply chain reconfiguration. This may account for many of the failures, which are experienced, in practice, during strategic realignment of dynamic systems.

In response to these concerns the principles of systems thinking, complexity and continuous system simulation have been presented in a context that fully acknowledges the contribution of operations management in the implementation phase of strategy. This has been illustrated using a simple example to show how even relatively elementary dynamic structures inherently contain the ability to display complex behaviour. Hence, the argument has been promoted that a structured approach to modelling, simulating, and experimenting with proposed strategic designs, at a preliminary stage, can often prove highly rewarding.

The author has also argued that strategic effectiveness requires a holistic view of the organisation and its competitive environment with an emphasis on complete business processes and avoidance of functional suboptimisation. This requires a multidisciplinary team approach with careful and imaginative system scoping and analysis. Furthermore, it is clearly desirable that the complex nature of organisational life is realistically accommodated (in so far that such a task is humanly possible) within the conceptual models that such teams create and apply during their analysis and decision-formulating activities. At very least, this usually requires a shift in paradigm from a linear, sequential, and quasi-steady-state perspective, to one, that accommodates nonlinearity, networked relationships, and truly dynamic behaviour.

However, the attainment of such a dynamic perspective is difficult, if not impossible, without recourse to appropriate information systems, ‘intellectual tools’, and corresponding support facilities. Here again the author has argued that the systems thinking, simulationist approach, can prove highly effective in bridging the gap between qualitative and quantitative approaches harnessing the strengths of both and mitigating respective weaknesses.

In conclusion, it is thereby argued that competitive advantage and ‘survivability skills’ can potentially be achieved through a process of OL that, in turn, leads to an enhanced ability to adapt quickly and successfully in complex, unstable environments. Furthermore, such outcomes may be enabled through improved decision-making and risk attenuation afforded by insights gleaned through the application of dynamic modelling and simulation concepts. Hence, although it is not possible to produce prescriptive, generic models and solutions for the strategy process, the dynamic modelling approach does provide a forum for craft-building strategies and evaluating, at least partially, potential outcomes. In this sense, the approach appears strongly oriented towards the emergent perception of strategy development and therefore highly appropriate in the existing, turbulent business environment.

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