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A Review of the Recent Contribution of Systems Thinking to Operational Research and Management Science

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Abstract

The systems approach, or systems thinking, has been intimately connected with the development of OR and management science initially through the work of founders such as Churchman and Ackoff and latterly through innovations such as soft systems. In this paper we have undertaken a review of the contribution that systems thinking has been making more recently, especially to the practice of OR. Systems thinking is a discipline in its own right, with many theoretical and methodological developments, but it is also applicable to almost any problem area because of its generality, and so such a review must always be selective. We have looked at the literature from both a theoretical and an applications orientation. In the first part we consider the main systems theories and methodologies in terms of their recent developments and also their applications. This covers: the systems approach, complexity theory, cybernetics, system dynamics, soft OR and PSMs, critical systems and multimethodology. In the second part we review the main domains of application: strategy, information systems, organisations, production and operations, ecology and agriculture, and medicine and health. Our overall conclusion is that while systems may not be well established institutionally, in terms of academic departments, it is incredibly healthy in terms of the quantity and variety of its applications.

Keywords: systems thinking, systems approach, complexity theory, system dynamics, soft systems methodology, cybernetics, critical systems, multimethodology

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A review of the recent contribution of systems thinking to operational research and management science

1. Introduction

The importance of systems thinking for OR/MS was recognised from the start by founders such as Churchman (Churchman 1963) and Ackoff (1962), systems engineers such as Hall (1962) and cyberneticians such as Beer (1966). However, as OR developed there was a degree of separation. OR itself tended to emphasise the mathematical and computer modelling approaches at the expense of systems thinking; cybernetics and system dynamics developed separately and somewhat in isolation; and the systems engineering/RAND approach was applied mainly in the US public sector. This fragmentation was challenged in the 1970s "crisis in OR" (Ackoff 1979; Checkland 1983) which led to the creation of soft systems/OR and critical systems. The most recent developments have been chaos and complexity theory.

This paper aims to provide a substantive review of the contribution of a wide range of systems thinking to OR and management science over the last decade. Given the vast extent of the systems literature, and that systems thinking can be applied in almost any domain, it is impossible to be in any sense comprehensive. In our research we have tried to spread our net as far as possible but we have concentrated in the main on practical applications of the systems approach rather than theoretical or philosophical debates. We have structured the paper into two main sections – the theoretical and methodological tools; and areas of application. The first section covers the systems approach and complexity theory, cybernetics, system dynamics, problem structuring methods (PSMs) and critical systems and multimethodology. In the application section the areas were defined as those most well represented in the literature search – strategy, IS/IT, organisations, production and project management, agriculture and environment, and health and medicine. There is inevitably a degree of duplication in doing it this way but we believe that readers may be coming at it either through particular methods or through application areas.

2. Theories and methodologies

2.1 General systems approach and complexity theory

2.1.1 History

The fundamental concepts of systems thinking were developed (in modern times) in the early part of the 20th century in disciplines such as organismic biology, ecology, psychology and cybernetics (Capra 1997). As a minimum they include: parts/wholes/sub-systems, system/boundary/environment, structure/process, emergent properties, hierarchy of systems, positive and negative feedback, information and control, open systems, holism, and the observer. The application of these concepts across many disciplines was recognised by von Bertalanffy (1950) and called general systems theory (GST). These ideas were taken up in OR/MS as management cybernetics (Beer 1967), system dynamics (Forrester 1968), systems engineering (Hall 1962) and what we might generally call the systems approach (Churchman 1968; Klir 1969; Weinberg 1975).

In this section we will limit ourselves to the systems approach itself, rather than its specialised components, and a more recent development - chaos or complexity theory (Kaufmann 1995; Waldrop 1992) - which is becoming increasing important in management thinking (Battram 1998; McMaster 1996). This originated in the physical sciences such as chemistry, physics and mathematics where it challenged the prevailing orthodoxy by being concerned with instability, non-linearity, discontinuity and chaotic behaviour. Practical examples are referenced in Table 1.

Table 1 Applications of the systems approach and complexity

2.1.2 Recent developments

The fundamental systems ideas have not changed significantly over the years, and there are many examples of applications, as will be seen in later sections, which simply employ "the systems approach". What they mean by this generally includes the following:

- Viewing the situation holistically, as opposed to reductionistically, as a set of diverse interacting elements within an environment;
- Recognising that the relationships or interactions between elements are more important than the elements themselves in determining the behaviour of the system;
- Recognising a hierarchy of levels of systems and the consequent ideas of properties emerging at different levels, and mutual causality both within and between levels;
- Accepting, especially in social systems, that people will act in accordance with differing purposes or rationalities.

Some more recent books expounding the systems approach are Gharajedaghi (1999), which sounds from the title as though it covers complexity theory but in fact is based on Ackoff's interactive design; Haines (2000) which is especially oriented to the strategy level; Gall (2002) which is an insightful and amusing look at the way systems work and fail to work; and Daellenbach and McNickle (2004) which is a management science textbook from a systems perspective.

Complexity theory developed during the 1970/80s in a range of disciplines – biology, chemistry, mathematics and economics. Traditionally, these hard sciences have assumed stability, equilibrium, linear change, cyclicality, robustness, simple models generating simple behavior (and vice versa). Chaos and complexity are the results of a Kuhnian revolution that emphasises instability, far-from-equilibrium, sudden change, sensitivity to initial conditions and complex behavior from simple models (and vice versa) (Lewin 1992; Mainzer 1997). Two questions emerge: to what extent do these insights apply to soft sciences and organizations (Byrne 1998; Cilliers 2000)? And, to what extent can complexity theory be encompassed within traditional systems thinking?

Complexity has been taken up enthusiastically within management theory and we can distinguish three broad areas:

- An organisation's environment is complex, characterised as a "fitness landscape" with non-linear interactions such as lock-in, increasing returns, punctuated equilibria and complex webs of interacting agents (Arthur 1994; Beinhocker 1997).
- Organisational strategy must change since the future is essentially unpredictable; markets do not attain equilibrium; and there may be sudden dramatic changes (note the credit crunch!) (Levy 1994; Stacey 2004).
- Within organisations there should be flat loose structures; networks of interacting, autonomous agents; periods of chaos should be expected; and patterns of behaviour may be "attractors" (Lewin and Regine 1999; Murray 1998).

Certainly there seems to be much evidence in our globalised world that many of these effects are indeed real. However, with regard to the second question we would argue that all of the complexity effects can be generated within the traditional systems thinking framework as resulting from particular patterns of, especially, positive feedback loops and networks of interactions between large numbers of relatively simple units. For instance, Mosekilde and Laugesen (2007) have shown that the Beer Game, a well-known feedback based management game, can display all the behaviour typical of complex systems.

2.2 Cybernetics

2.2.1 History

The modern notion of cybernetics as a discipline was established by Wiener, McCulloch, Ashby and others and was mainly seen as the scientific study and mathematical modelling for an understanding of regulation and control in any system (Ashby 1956; Wiener 1954; Wiener 1958). Cybernetics studies the flow of information through a system and the way in which that information is used by the system as a mean of controlling itself (Ashby 1956). Today, cybernetics has a broad range of areas of application, including biocybernetics, biomedical systems, artificial intelligence, robotics, adaptive systems large-scale socio-economic systems, man–machine systems, and systems science (Johannessen 1998; Rudall 2000; Tilebein 2006; Vallee 2003), —all of which are based on Wiener's interdisciplinary cybernetics concepts.

Stafford Beer is acknowledged as the first to explicitly apply the principles of cybernetics to management and claim its relevance to OR (Beer 1959a; Beer 1959b). Defining his project as the 'science of effective organization', he argued that the cybernetic principles can be applied to all types of organizations and institutions, and to the interactions within them and between them, with the objective of making these systems more efficient and effective. He also claimed that cybernetics is the basis of control in any systems and thus provides the foundation for defining organizational control (Beer 1959b; Green and Welsh 1988).

The main manifestation of Beer's work and reflections on management cybernetics is the Viable Systems Model (Beer 1972; Beer 1979; Espejo and Harnden 1989). The VSM is an abstract model of the organizational structure of any viable or autonomous system. The model aims to specify the minimum functional criteria through which an organization can be said to be capable of independent existence or to maintain its identity in a changing environment. It was developed to diagnose the deficiencies in an existing organizational system, and it was believed that the behavior of a whole system could be represented and understood through modeling the dynamical feedback process going on within them. One of the prime features of a viable system that survives is that they are adaptive or capable of learning.

2.2.2 Recent developments

There are many themes in Beer's oeuvre on management cybernetics that are a constant thread and only three of these will be highlighted here. These are communication, variety and participative management.

The first of these themes is drawn from the work and insights of Bavalas (Bavelas 1950; Bavelas 1951; Bavelas 1960), who, in terms of the relational structures, described an understanding of how an organization can communicate with itself. One of Bavelas's main insights is the paradox of peripherality (autonomy) versus centrality(control) of actors in an organization (Bavelas 1950; Bavelas 1951). This insight led Beer to claim that centralised systems often do not work (Beer 1979) and was further developed in 'The Heart of Enterprise' (Beer 1979) and later refined in 'Beyond Dispute' (Beer 1994). This issue has been a common theme for cybernetic research of social systems, particularly in the area of governance (Leonard 2006; Turnbull 2002).

The second theme –variety, is defined by Beer as 'the total number of *possible* states of a system, or of an element of a system' (Beer 1979). Drawing on Ashby's Law of Requisite Variety (LRV) Beer was concerned with the complexity inherent in organisations as they are affected by the environment they are in, creating the possibility of great uncertainty. The activities and management of organisations should be such that identifies the minimum number of choices needed to resolve uncertainty. Beer claimed that the LRV is fundamental to matching resources to requirements in organizations and to the measurement of performance. He also claimed that it can be used allocate the management resources necessary to maintain process viability or survival. There are many examples of the use of the LRV in the management science literature covering a range of topics such a strategic planning, production and control, and the environment (Espejo 1993; Fransoo and Wiers 2006; Lewis and Stewart 2003; Love and Cooper 2007; Nechansky 2008)

The third theme is participative management. Beer was concerned to ensure that every member of an organization and every person who to a greater or lesser extent communicates or interacts with it is involved in the organization's matters (Beer 1974). Participation management builds on the two themes described above and is concerned with seeking more effective ways to manage the complexity that would arise with an increase in communication (Espinosa et al. 2004). This would require people within the organisational setting to have adequate autonomy in order to prevent the hazardous inadequacy of a richly connected system. Beer consistently argued for decentralisation and devolved decision-making, and that as much autonomy as possible must be provided to the lower levels of the organization which would deploy requisite variety effectively. His ideas about decentralisation, devolved decision-making and human relations (Beer 1979) were viewed as an antidote to conceptions of scientific management at the time (Espejo and Harnden 1989).

Other developments in management cybernetics include von Foerster's work on second order systems (Foerster 1968; Foerster 1984; Foerster and Poerksen 2002). More recently, much has been made of the advent of computing technology and re-emergence of cybernetics over the last 20 years (Rudall 2000; Rudall 2002). More generally, areas such as fuzzy logic, genetic algorithms, neural networks, and adaptive systems, which were relatively unexplored thirty or even ten years ago, are now dominating the scope of cybernetics and OR (Dowsland 1996; Kobbacy et al. 2007; Rudall 2004; Rudall and Mann 2008; Tilebein 2006).

At the more theoretical level, management cybernetics has to some effect been influenced by concepts developed by Maturana and Varela (Maturana and Varela 1980; Maturana and Varela 1987). The authors realized that the cybernetic metaphors which had been based on biology rendered a conception of the autonomy of the living being impossible. They proposed the idea of autopoiesis which they describe as the process by which a system, organization, or organism produces and replaces its own components and distinguishes itself from its environment (Maturana and Varela 1980; Mingers 1995). In recent years, their work has extended beyond the domain of biology and is now used broadly across a range of different disciplines and fields of enquiry (Mingers 1995). The possibility that autopoiesis could also account for social forms of organization, remains an object of debate among academics on self-organization (Mingers 1992a; Mingers 1995; Mingers 1997b; Mingers 2002; Mingers 2004).

One major development in Beer's work, which draws on the three themes described earlier, is Team Syntegrity (TS), and it follows on from his endeavour on the VSM (Beer 1994; Espinosa and Harnden 2007). While the idea developed from the insights on communication and decision-making in groups drawn from the work of Bavelas (Bavelas 1950), it was also a response to some key questions relating to the development of non-hierarchical, democratic organizations able to self-organize and work cooperatively. In particular, he was interested in exploring how to integrate distributed knowledge in order to develop shared knowledge as a means for guiding actions.

Applications of cybernetics, the VSM and TS are wide spread (see Table 2). TS will be illustrated by a recent application. The example is of a project for developing a strategy for getting the community involved in a local area health initiative in London, UK (White 2003). The aim was to develop a strategy which would also highlight how to ensure that the community was involved in the design, development and delivery of the initiative, and also to develop insights that would be of value to practitioners. This was seen as central to developing and implementing appropriate and effective health and related services in order to meet local needs. It is often claimed that groups are more likely to be creative when they comprise people with different backgrounds and different points of view (Beer 1994; Bunker and Alban 2006; Senge 2006; White 2002). However, it could be equally argued that high levels of diversity could inhibit cohesiveness where the potential for antagonism exists (Beer 1981; Beer 1994; Beer 2004). TS was used for the study to help to balance the antagonism exhibited by some of the members of the group with mutual motivation. It was found that this method is particularly useful when a wide range of perspectives need to be brought to bear on a complex issue, and it is particularly powerful when people admit that they do not know the answer but want to work together to find creative and viable solutions. Some of the participants at the end of the study reported that a 'qualitative change' had taken place. This phenomenon has been noticed by other authors (e.g. (Phillips and Phillips 1993) as well as Beer (Beer 1994), who pointed out how certain feelings or characteristics spread throughout a large group or how the life of the group can take a sudden and dramatic turn.

Table 2 Applications of Cybernetics

2.3 System dynamics

2.3.1 History

The fundamental ideas of system dynamics were developed by Jay Forrester at MIT in the 1960s. He was interested in modelling the dynamic behaviour of systems such as populations in cities and industrial supply chains (Forrester 1961; Forrester 1969). He argued that the behaviour of such systems, at whatever level, resulted from underlying structures of flows, delays, information and feedback relations. These generated typical patterns of growth, decay, oscillation or chaotic behaviour that was often counter-intuitive. Forrester's approach was to model the relationships between the various systems components, express these as differential or difference equations, and then run the model as a computer simulation.

At first system dynamics (SD) was very successful, with more and more ambitious models being developed culminating in the Club of Rome sponsored model of the world economy (Meadows et al. 1972) that was one of the first to predict restrictions on growth caused by lack of world resources. However, this report was extensively criticised for its data and assumptions (e.g., (Solow 1972)) and for a period SD went into decline. In recent years it has come to the fore again, partly through the popularity of Peter Senge's book *The Fifth Discipline* (Senge 1990) which advocated systems thinking and the basic ideas of SD as part of the "learning organization" approach, and partly because of the development of powerful, easy-to-use computer software such as *iThink* and *Powersim*. Good modern introductions can be found by Vennix (1996) and Sterman (2000).

2.3.2 Recent developments

System dynamics provides a very powerful set of concepts for understanding and modelling complex systemic behaviour that has been taken up in a wide range of application areas. At its heart it concerns the results of the interplay of two forms of feedback loop – positive or reinforcing loops that lead to continual growth or decay, and negative, balancing loops that lead to stability. These loops, and the patterns of behaviour they generate, can be found in systems of all types hence the wide range of applicability. There are two main stages in the process – identifying and mapping the causal loops and then quantifying them and building and testing a computer model. Work often may stop at the first stage with the production of a causal-loop (sometimes called influence) diagram where the aim of the project is simply greater understanding of the situation, or where reliable quantitative information is not available. This is sometimes referred to as qualitative as opposed to quantitative SD (Wolstenholme 1999b). Table 3 lists recent SD applications in a range of different domains.

Table 3 applications of system dynamics about here

By way of a recent example, we can consider an investigation of broadband take-up in rural Scotland (Howick and Whalley 2008) went as far as developing a quantified simulation model. Broadband is seen as having significant economic benefits, especially in remote areas, but despite its widespread availability there is still a rather patchy take-up. The researchers developed a detailed influence diagram including factors such as: understanding and appreciation of broadband, costs, financial benefits, advertising, and specific policy interventions. This was developed into a full SD model and populated with a range of data and estimated relationships. The model was extensively tested for validity and reliability. The key factor that came out of the model was the importance of targeting those families that consciously thought that they did not want the internet or even a PC at all as they restricted the pool of potential entrants.

Two recent developments in SD will be discussed – the prominence of generic structures or archetypes (Lane 1998), and efforts on behalf of SD to become less isolated and link more to other disciplines.

SD has always held the view that there are particular patterns of feedback that occur in many situations and generate particular patterns of observed behaviour – Forrester maintained that there may be around 20 such generic structures, for example product launches or urban development (Forrester 1969). This idea was reinterpreted by Senge (1990) in terms of "systems archetypes" which often explain organisational problems, for example "success to the successful" in which reinforcing loops differentiate between competing organisations so that one becomes ever more successful at the expense of the other; or a "fix that fails" where a short term fixes generates new and unforeseen problems that require even more of the fix.

This can be illustrated by a project for a police force in W. Yorkshire (UK) (Newsome 2008) who were concerned to understand better the complex interactions between resourcing particular forms of activity and overall results in terms of the crime level and crime detection. A high-level system dynamics model was developed to look at the three main forms of police activity – responsive crime detection, proactive investigation, and prevention and reassurance – and the effects of how much resource is put into each of the activities. This led to seeing the situation of an example of the "shifting the burden" archetype where short term measures to improve a problem appear successful but thereby actually undermine the more fundamental solutions. From this one could see that the Force's concentration of resources on response activity was driving down the crime rate in the short term but in the longer term the lack of proactive investigation and prevention activities would push the underlying level of criminal activity back up. More resources needed to be ring-fenced for these other activities.

More generally, system dynamicists have recognised that over the years since its inception system dynamics has become rather isolated both from mainstream management areas and more general disciplines such as social theory even though many of the basic concepts have become almost ubiquitous (Repenning 2003). Within management, significant links are being forged to both soft systems/PSMs and the strategy area. A major conference was held in 1994 at Stirling where the main aim was to bring together SD researchers, especially from the US e.g., Forrester and Sterman, with soft systems and OR proponents such as Checkland and Eden. This was seen as being very successful (Morecroft and Wolstenholme 2007) and there has certainly been work combining SD with other systems approaches such as SSM (Paucar-Caceres and Rodriguez-Ulloa 2007a) and cognitive mapping (Ackermann et al. 1997). Andersen et al (2007) argue that SD-based group model building should be seen as a problem structuring method. SD has also been used within the strategy area for many years and this promises to become much more significant with the publication of several major books (Morecroft 2007; O'Brien and Dyson 2007a; Warren 2007).

Finally, there have been efforts to generate interest in SD from social scientists more generally. Lane(2001a; 2001b) has explored where SD fits in with traditional social science paradigms such as positivism and interpretivism. He concludes that it is difficult to place as it has aspects of both, but that it has strong affinities with social theories that try to integrate agency and structure such as Giddens. This relates to the debate as to whether SD should be seen as "hard", i.e., building models *of* external reality, or "soft", i.e, modelling peoples' subjective perceptions (mental models) (Lane 2000). Mingers (2000a) supports this, arguing that SD exemplifies a particular philosophical perspective – critical realism – which involves both an integration of agency/structure and an epistemological balance between objectivism and subjectivism.

2.4 Soft systems and problem structuring methods (PSMs)

2.4.1 History

Problem structuring methods (PSM) are a family of interactive and participatory modelling approaches whose aim is to assist groups of diverse composition to alleviate a complex, problematic situation of common interest. This situation is characterised by the existence of multiple actors, multiple perspectives, incommensurable and/or conflicting interests, prominent intangibles, and key uncertainties (Mingers and Rosenhead 2001; Mingers and Rosenhead 2004). Typically, the hardest and most demanding element in addressing such situations can be the framing and definition of the issues constituting the problem. PSMs offer support in such situations through modelling and group facilitation with a view to stimulating dialogue and deliberation about the problem domain, and reaching shared understanding and joint agreements with respect to it. Perhaps the most popular of the methods is Soft Systems Methodology (SSM). Its history and development elides significantly with PSMs in general, and thus the focus of this section will be on SSM. From the systems field, however, mention should be made of interactive planning (Ackoff 1993), social systems design (Churchman 1968), and strategic assumption surfacing and testing (Mason and Mitroff 1981; Mitroff and Mason 1981) as being very similar to PSMs.

The background to SSM an approach to systems thinking is well established (Checkland 1999a; Mingers 2000b). It was developed in response to the perceived failure of traditional systems engineering (SE), particularly with regards to management problems. Whereas, traditional SE develops systems by considering the purpose or objective, then working backwards to find ways of achieving that objective, often via a device of a (mathematical) model which pursued an objective from a declared point of view, SSM was developed as a result of the failure of this approach in many management situations. The pioneers of SSM found that in many situations the questions 'what is the objective?' and 'what are we trying to achieve' were part of the problem (Checkland in (Mingers and Rosenhead 2001) pg 66). Without an agreement on objectives, or if the objectives are badly defined, then the results of traditional SE would be loss of confidence in the model and, most likely, lead to dissatisfaction on the part of those whose view of the objectives is not implemented. Thus, the primary contribution of SSM is in the analysis of complex situations where there are divergent views about the definition of the problem. SSM was developed as a means for understanding and dealing with the diversity of views and interests.

The core ideas of SSM are elementary and by now familiar. SSM is a methodology and as a learning system (Checkland in (Mingers and Rosenhead 2001)) which can be used both for general problem solving and in the management of change. To intervene in such situations SSM uses the notion of a "system" as an interrogative device (through developing rich pictures and root definitions) that will enable debate amongst concerned parties. In its 'classic' form the methodology consists of seven steps, starting with an initial appreciation of the problem situation leading to the modelling of several human activity systems (through root definitions) that are thought to be relevant to the problem situation. By discussions and exploration of these, the decision makers will arrive at accommodations (or, exceptionally, at consensus) over what changes may be systemically desirable and feasible. Recent revisions give a more sophisticated and flexible view of the process (Checkland and Scholes 1990; Checkland and Winter 2006), which brings together two streams of enquiry – cultural analysis and logic-based enquiry. As a result, more attention is paid to locating the methodology in respect to its philosophical underpinnings (Jackson 2001; Mingers 2000b), which reinforces the view that SSM represents a different epistemology to traditional systems engineering, in that it is claimed that the system should not be viewed as some part of the world which is to be engineered or optimised, but instead should be seen as a process of enquiry, that is, the notion of a system is no longer applied to the world but is instead applied to the process of dealing with the world.

2.4.2 Recent developments

SSM remains the most widely used and practical application of systems thinking (de Water et al. 2007; Ledington and Donaldson 1997; Mingers 2000b; Reisman and Oral 2005) (see Table 3 for range of applications). The methodology has been described in several books and many academic articles. There are now several hundred documented examples of the successful use of SSM in many different fields, ranging from ecology, to public services and business applications. (de Water, Schinkel et al. 2007). It is also widely acknowledge in the Information Systems field (Checkland and Holwell 1998a; Wilson 1998). Despite revisions to the methodology (Checkland and Poulter 2006), it is the classical view of the methodology which is most widely used in practice (Ledington and Donaldson 1997) outside of the Lancaster School where it originated (Mingers 2000b).

In most reviews of SSM, it is the possibility of change in practice, the focus on stakeholders and their views, and the process as learning that are crucial to SSM and at the same time present several areas of difficulty for the use of the methodology in practice (Jackson 2001; Pala et al. 2003). There is, for example, continued criticism of the approach in how to deal with relative views and so on. Later publications go some way to resolve this (Checkland in (Checkland and Winter 2006; Mingers and Rosenhead 2001). However, it was through highlighting the problems and limitations of the approach that users of SSM started to revise the process and/or test its use in new situations (Mingers 2000b).

Recent interest has been focused on using the approach to tackle major problems (Jackson 2001), where there is a continued recognition that traditional SE and soft systems thinking are important and that together they may bring significant developments to problem solving (Wierzbicki 2007; Winter and Checkland 2003). Thus, it can be assumed, without controversy, that these problems are generally complex, and in order to deal with them there needs to be some contribution by both approaches. It is also now fairly well understood that tackling complex problems may involve different phases and therefore different methods may be appropriate at different points in the whole business of dealing with the problem. These conditions provide a backdrop to recent developments in SSM and can be captured by the following themes. The first theme relates to the fact that SSM has been adopted by many organisations and incorporated into other approaches (Mingers 2000b; Mingers and Brocklesby 1997; Ormerod 1995a). In fact many practitioners have used SSM in parts and/or with other approaches (Mingers and Brocklesby 1997; Munro and Mingers 2002b). Researchers have recognised that this development is quite important but theoretically under-researched, and there have been various attempts at providing guidance for combining different methodologies (Mingers and Gill 1997a).

The second theme is related to first in that the distinction between hard and soft systems has come under scrutiny (Lane and Oliva 1998; Pidd 2007), with some researchers arguing that the distinction is artificial (de Water, Schinkel et al. 2007). It may depend on how the approach is used and the extent to which it is used in a soft or hard way. Some researchers have explored using SSM with more formal modelling approaches either in terms of an integrated approach (Lane and Oliva 1998; Paucar-Caceres and Rodriguez-Ulloa 2007b) or in combination (Kotiadis and Mingers 2006a), while others claim more pragmatic reasoning for combining the hard with the soft (Ormerod 2006a). This development can be seen in the growing number of papers which have integrated or combined SSM with approaches such as simulation or DEA (Lehaney and Paul 1996a).

The final theme is around a growing interest in understanding and exploring the design of the intervention itself. This builds on the perennial view that if operational research (in particular PSMs) is to have a significant role and influence, it needs to come closer to the actual concerns of practitioners (and stakeholders) (Franco et al. 2007). There is also the problem of being an expert in PSMs or how individuals may effectively learn about their use (Keys 2006). In relation to the first issue on designing an intervention, it was suggested in a recent paper, that SSM is a methodology used to support and to structure thinking about, as well as intervening in, complex organisational problems (Checkland and Winter 2006). In relation to the issue on expertise, Keys suggested the need for designing and providing a suitable learning environment in order to understand the nature of being an expert user of PSMs (Keys 2006; Keys 2007).

Table 4 Applications of SSM and PSMs

2.5 Critical systems and multimethodology

2.5.1 History

By the 1980s there were a whole range of Soft OR/systems methods and a new question emerged – which method should be used when (Jackson 1989)? At the same time a third paradigm within systems began to develop known as Critical Systems Thinking (CST) or Critical Management Science (Jackson 1985; Mingers 1980; Mingers 1984; Mingers 1992b; Ulrich 1983). This drew on the work of both Churchman (1971; 1979) and the sociologist Habermas (1978) and revolved around two meanings of the term "critical". The first dimension, drawing on Kant (1933), was epistemological and was concerned with the nature and limits of knowledge, and investigated the assumptions and limitations of both traditional hard systems, and the newer soft systems. From this developed frameworks (Jackson 1989; Jackson 1990) and a meta-methodology known as total systems intervention (TSI) (Flood and Jackson 1991) for choosing appropriate methods to use in a particular situation. The second dimension was more political and debated the nature and role of OR within society as a whole (Jackson 1991; Jackson 1993; Mingers 2000d) following on from earlier concerns about the social responsibility of OR (Ackoff 1974a; Chesterton et al. 1975; Rosenhead and Thunhurst 1982).

The epistemological debate eventually moved from the question of selecting a single method to recognizing the value of combining together different methods, not just soft but especially employing both hard and soft methods together. This is known as multimethodology (Mingers 2000c; Mingers 2006; Mingers and Gill 1997b) or coherent pluralism (Jackson 1999; Midgley 2000). It is argued that this allows the practitioner to address both the quantitative and qualitative aspects of a complex situation and that different methods can better address the different phases of an intervention.

2.5.2 Recent developments

The development of critical systems, and especially multimethodology, has been a major step forward for OR/MS in providing the freedom for practitioners not to be confined to a particular method or even paradigm but to be able to use different methods as necessary in an informed and effective manner. It mirrors changes in social science more generally where the paradigm-silo mentality is now being replaced by mixed-method research as the norm (Tashakkori and Teddlie 2003).

In theoretical terms there has been considerable debate about a proper process or meta-methodology to help with the choice and combination of methods. Mingers (1997a; 2003) has developed several frameworks that allow the free combination of both methodologies and parts of methodologies underpinned by Habermas's theory of communicative action (Mingers 2006), and Bhaskar's critical realism (Mingers 2000a). Jackson is concerned at the idea of unreservedly combining methods across paradigms because of the significantly different philosophical assumptions that underlie them. His coherent pluralism approach (Jackson 2003b) involves combining methods from within a generic paradigm, but then using several paradigmatic lenses to get different views of the problem. Midgley (2000) is happy to combine methods across paradigms but is more concerned with the actual process and in particular the question of how the boundaries of the project are drawn. Whatever boundaries are drawn, some actors will be included and their viewpoints recognized, while others will be excluded and thus not be able to influence the project. He has developed a method of "boundary critique" to try and deal with this problem.

Another author concerned with boundaries is Ulrich who draws heavily on the work of Churchman and Habermas to develop an approach called critical systems heuristics (CSH) (Ulrich 1994) which is a set of questions for challenging the boundaries drawn by experts and planners. There has been a debate with Jackson as to whether CSH should be seen as one methodology among many others or as part of the process of structuring the problem prior to choosing methodologies (Jackson 2003a; Ulrich 2003). Ormerod has contributed to the debate from more of a practitioner's perspective (Ormerod 2004) as well as describing several sophisticated multimethodology interventions (Ormerod 1995b; Ormerod 1996a; Ormerod 1999a).

In practical terms there is now a considerable amount of work in the critical systems (CST) and multimethodology traditions. Some examples from CST and TSI are: IS planning (Cordoba and Midgely 2006), knowledge management (Gao et al. 2003), quality management (Houston 2007; Taiwo 2001) and designing a user support service (Warren and Adman 1999). There are now many examples of multimethodology applications (Munro and Mingers 2002a). Although they often involve either hard methods or soft methods but not both, increasingly combinations across the paradigms are occurring as well. Some examples of the latter are: combining data envelopment analysis (DEA) and group support systems (GSS) (Casu et al. 2005), multi criteria decision analysis (MCDA) with conflict analysis (Losa and Belton 2006), cognitive mapping with system dynamics (Ackerman et al. 1997), DEA with SSM (Mingers et al. 2009) and simulation with SSM (Kotiadis and Mingers 2006b).

3. Areas of application

3.1 Strategy

Systems thinkers have long been interested in strategy. Indeed some of the early texts on strategic planning were written by prominent systems experts (Ackoff 1970; Ansoff 1965; Churchman 1968). A casual glance at these early works would seem to give the impression that systems thinking and strategic thinking were almost synonymous. Indeed, it is currently argued that OR/systems thinking has much to offer in strategic planning or development (Pidd 1996; Pidd 2004). Ackoff was primarily the first to propose an explicitly systems approach to strategic or corporate planning. His major contribution was to argue that strategic decisions are messes, often characterised as an interactive systems of related issues (Ackoff 1970; Ackoff 1974b; Ackoff and Emery 1972). Others have also highlighted this observation where, for example, the context for strategy has been defined as wicked problems (Rittel and Webber 1973). From the systems literature, Ackoff (with his concept of corporate planning) provided one of the first recipes for a rational approach required to develop strategy. Nowadays, systems thinking in strategy has incorporated ideas from complexity theory, particularly seeing strategy as 'order out of chaos', and regard strategic decision making as complex, involving different issues and many interacting factors and stakeholders (Aligica 2005; Broman et al. 2000; Floyd 1999; Houchin and MacLean 2005; Mason 2007; Stacey 1995).

There are many different ways in which the term strategy is used. The most commonly used definition and categorisations of the strategy processes follow mainly from Mintzberg. He summarises the definitions of strategy as the 'five Ps' (plan, ploy, pattern, position and perspective) (Mintzberg and Quinn 1996). He also categorises the strategy making process in terms of entrepreneurial, planning adaptive, ideological and grass-roots (Mintzberg and Waters 1985). These are based on considerable historical and empirical work on what strategy is and how it is formed. Most often, though, the process of strategy making has been simply referred to as of two modes (Pidd 2004): planned and emergent. The planned mode has often been attributed to the systems thinkers such as Ansoff and Ackoff (Ackoff 1970; Ackoff 1981a; Ansoff 1965; Ansoff 1979). This is a rational view of strategy and depends on the analysis of environmental opportunity and threats, and the strengths and weaknesses of the organisations (Dyson 2000a; Dyson 2000b; Dyson 2004). Proponents of this approach can also be found in the OR and systems literature (Pidd 1996; Pidd 2004; Powell and Powell 2004; Powell and Bradford 2000; Powell and Coyle 2005). They are particularly concerned in demonstrating ways in which more analytical approaches based on a system perspective can benefit strategy development (Clark 1992; Clark and Scott 1995; Fowler 2003; O'Brien and Dyson 2007b) and the use of visioning techniques and scenario analysis (O'Brien and Meadows 2001; Powell and Powell 2004). Mintzberg points out that this mode assumes that formal analysis can provide an understanding of the environment sufficient to influence it (Mintzberg 1994). This mode is also associated with large companies and with the teaching methods or consulting styles of MBA programmes.

The more incremental or emergent approaches were seen as a response to the inadequacies of the planning approaches. They are invariably referred to as muddling through (Lindblom 1959; Lindblom 1979), adaptive (Mintzberg and Quinn 1996) or ad hoc reactive (Mintzberg and Waters 1985; Peters and Waterman 2004). Here strategy development was assumed to be so complex in time that the whole could not be grasped. Thus more incremental approaches working in small steps are essential for learning and adapting strategy over time. There is much debate (Ansoff 1991; Mintzberg 1991) on the validity of the planning mode in comparison to the more adaptive and event emergent approaches.

From a systems thinker's point of view it could be accepted that one process mode cannot be optimal for all situations and therefore a contingency approach may appear more feasible (Ormerod 2006b).

In terms of the incremental or emergent approaches, one of the major contributions from systems thinking can be found in Ackoff's work on interactive planning (Ackoff 1974b; Ackoff 1993), which requires continuous dialogue with key stakeholders, where top managers play a role which is empowering and enabling particularly in the process of transacting between all members of the organisation who are viewed as participants and whose role is to learn and improve. Thus, he argued that strategy making should be participative and continuous and reflect learning (Ackoff 1981b; Ackoff 1998). Some systems thinkers have had or have built on these insights (Mason and Mitroff 1981; Ormerod 1996b; Ormerod 1997; Ormerod 1998), while others have argued that SSM, which is similarly concerned with participation and learning, is suited for strategy development (Connell 2001; Gregory and Midgley 2000; Jackson 2001; Mingers 2000b). There is also growing literature in which another systems approach- system dynamics- applied to strategy has flourished (Fowler 2003; Lyneis 1999; Powell and Bradford 2000; Powell and Coyle 2005; Warren 2004). Recent developments in this area (drawing on (Senge 2006)) emphasise the notion of organisational learning (Bianchi and Montemaggiore 2008; Dangerfield and Roberts 2000; Lyneis 1999; Lyneis et al. 2001; Vennix 1995; Vennix 1999). There is also a growing interest in large group or 'whole systems' methods (White 2002), particularly in public sector policy development.

A more recent development in strategy is in taking into account the cultural factors that affect the ways of doing things in organisations (Johnson 1992). This strand has continued to be influenced by OR and systems thinkers (Eden 1992; Eden and Ackermann 2000). It is suggested that there is a need for techniques to surface managers' strategic and cultural assumptions, and to provoke debate or use outsiders as change agents to implement necessary strategic change. Finally, researchers have also addressed issues of competences and capabilities and in particular how they are built over time (Eden and Ackermann 2000; Ormerod 2008; Porter and Kramer 2006).

3.2 Information systems and knowledge management

To what extent is the systems approach evident in the IS/IT literature? At one level one could say that systems thinking is at least implicit in most IS research. The discipline is called information *systems* after all, and I suspect that few academics would say they were reductionists, or deny that they ultimately assume a systems approach. However, the number of papers that formally or explicitly claim to use systems theory is actually relatively small leading Alter (2004), who argued for a systems thinking approach as opposed to a "tool thinking" approach within IS, to title his paper "Desperately seeking systems thinking in the IS discipline".

As in the previous application areas, we can find examples drawing on the main areas of systems thinking – complexity, GST, SSM and cybernetics – although not system dynamics. Xu (2000) provides a reasonable overview. Beginning with general systems concepts and GST several authors are concerned with using ST to improve the integration of the discipline either overall (Mora et al. 2007); with regard to research methods (Mingers 2007); or in developing actual IS systems (Garrity 2001; Wainwright and Waring 2004). Porra *et al* (2005) examined the history of Texaco's IT function using GST, interestingly using several different "lenses" thus showing that GST can be used in an interpretive manner, while Wennberg *et al* (2006) used GST to examine information security within Swedish pharmacies.

Complexity and chaos theory have also been used to provide new lenses with which to view organisations and information systems within them (Courtney et al. 2008). Vidal and Lacroux (1999) argue that in a complex society become decentred, away from a single decision-maker with a particular problem towards a nexus of participants/ organisations/ problems. This means that an important function for an IS is *intermediation* between such elements, in particular between individuals, organisations and reality. McBride (2005) uses complexity concepts such as "strange attractors" and the "edge of chaos" to better understand the history of the development of an IS strategy within the UK Probation Service. Samoilenko (2008) uses concepts such as "fitness landscapes" and "self-organization" to suggest improvements to ISD methodologies.

Finally we will consider the contribution of two related approaches – SSM and Churchman's dialectical inquiring systems. These are related in that Checkland (1999b) drew on Churchman's work on dialectical systems in developing SSM. Churchman was one of the founding fathers of both OR and systems thinking and his major work was *The Design of Inquiring Systems* (Churchman 1971) which considered systems for generating knowledge from different philosophical perspectives, especially Hegelian and Singerian. This has led to s stream of work exploring these approaches within the context of DSS (Courtney 2001), knowledge management (Richardson et al. 2006), and e-business (Bajgoric 2006).

SSM has had a long history of application within information systems from one of Checkland's earliest papers (Checkland and Griffin 1970) through to one of his more recent books (Checkland and Holwell 1998b). Considerable work was done on linking SSM to more conventional systems development methodologies (Bustard et al. 2000; Mingers 1988; Stowell 1995) particularly in the area of requirements definition. This has led to the generation of a range of specific IS development methodologies based primarily on SSM such as Multiview (Wood-Harper et al. 1985), CLIC (Champion et al. 2005) and SISTeM (Atkinson 2000). We can also find examples of the use of SSM in specific areas such as information system failures (Yeo 2002) and the validation of IS (Petkova and Petkov 2003). Finally, SSM has been suggested as an alternative paradigm within information systems – Hirschheim *et al* (1997) suggest it as an alternative to the mainstream approaches such as structured systems design, and Vo *et al* discuss three systems thinking approaches (SSM, Senge' *Fifth Discipline* (Senge 1990), and Mitroff and Linstone *Unbounded Thinking* (Mitroff and Linstone 1993)) as paradigms for developing IS education.

3.3 Organisations and corporate social responsibility

There are many ways in which systems thinking has been applied to the study of organisations. Firstly and most obviously, systems theory has been developed within sociology and has been one of the main theoretical traditions in social theory on organisations. Thus, systems approach has been fundamental to organisational theory. Burrell and Morgan provided the first comprehensive study of the use of systems models of organisations and their equivalent theoretical foundations (Burrell and Morgan 1979). From this we can surmise that the early impetus for systems theory and organisational theory can be found in Parson (open systems model), Emery and Trist (Emery and Trist 1973)(socio-technical systems), Katz and Kahn (Katz and Kahn 1978)(adaptive systems). The adoption of systems theory characterised the organisation in the way they exchange resources, and adapt ideas such as feed-back and input-output. Some of these ideas came under critical review. The most coherent attack on the functionalism of these systems ideas as explanations for organisations was delivered by Silverman (Silverman 1972)). The links between Social theory, systems ideas and organisations were further developed by Luhmann who was inspired by Parsons'systems approach, but noticed several inconsistencies that led him to base his theory on communication rather than action and autopoiesis (for a critical overview of Luhmann's ideas see Mingers (Mingers 1995)). There are many applications of Luhmann's ideas to organisations and in areas such as governance and public administration eg (Buchinger 2006; Dunsire 1996; Kickert 1993), and the environment (Entwistle 1999; Vanderstraeten 2005), Education (Vanderstraeten 2002) and IS (Cordoba 2007).

The second area in which systems ideas have been applied to organisations is in organisational redesign or restructuring. There has been a long tradition in the applications of the VSM and SSM and there are many recent examples in a variety of fields (Assimakopoulos and Dimitriou 2006; Dodis and Panagiotakopoulos 2007; Espejo and Harnden 1989; Herrmann et al. 2008; Ragab and Awad 2003; Yusof et al. 2001). Finally, Complexity thinking has been applied to organisation structures and processes, specifically to design an organisation for a complex world (Haynes 2008; Lewin and Regine 1999; Mason 2007; Murray 1998; Schwaninger 2000).

Without being controversial, corporate social responsibility (CSR) can be defined as how organisations and businesses align their values and behaviour with the expectations and needs of different stakeholders (Lee 2008; Schwartz and Carroll 2003). CSR demands that organisations and businesses manage the economic, social and environmental impacts of their operations in order to maximise the benefits and minimise the downsides for their stakeholders(Gregory and Midgley 2003; Zwetsloot 2003). Essentially it is about how organisations and businesses take account of its economic, social and environmental impacts in the way it operates (Porter and Kramer 2006). Specifically, systems thinkers such as Ackoff see CSR as actions that an organisation can take to address both in its own interests and the interests of wider society (see (Ackoff and Rovin 2003)). However, the complexities apparent in CSR theory and practice have led to a criticism that organisations engage with CSR despite being unsure of whether it is in the best interests of their business, society or both (Aguilera et al. 2007).

Recent attention by systems thinkers to CSR conclude that CSR, while viewed as important it does not means the same thing to everyone (Cordoba and Campbell 2008b; Gregory and Midgley 2003). However, the widespread acceptance and growth of CSR in business and society has brought to bear key issues including governance, environmental management, stakeholder engagement, labour standards, employee and community relations, social equity, responsible sourcing and human rights (Schwartz and Carroll 2003). A recent special issue on systems thinking and CSR highlighted that CSR is predicated upon understanding multiple perspectives and relationships and that the field would benefit from the use of systems thinking and methods (Cordoba and Campbell 2008b). For example, for organisations, CSR is asked to answer questions not only about production and services, but also of other collateral effects or by-products, such as how the stakeholders become engaged to address CSR concerns in a given organisational setting (Arias 2008). In this regard, it is claimed that engagement with the organisation is central to enhance the CSR from a systems perspective (Gregory and Midgley 2003; Knez-Riedl et al. 2006; Maon et al. 2008). The resolution of specific problems in the context of CSR can be addressed in terms of a participative process involving the organisation and its stakeholders (Arias 2008; Porter 2008). This would address what frequently takes the form of a 'wicked problem' or of 'mess' where agreement on values is unlikely (Ackoff and Emery 1972; Checkland 1981; Rittel and Webber 1973). There seems, therefore, to be scope for systems methodologies to address differences in stakeholders' concerns and carefully combine them (Porter 2008). In particular SSM has been suggested as appropriate (Cordoba and Campbell 2008a).

There are two important and interrelated paths leading to the core of CSR. The first perspective comes from interest in the aspect of sustainable development that regards the role of business and industry, and is often described as 'triple bottom-line reporting'. The second path is CSR's origin in *business ethics*, which has a long tradition both within academics and business itself. Research into systems thinking and these two paths is burgeoning. In relation to sustainable development, there is a concern to address, from a systems perspective, the dilemmas of addressing triple bottom line interests in economic, social and environmental issues (Elkington 1994). Research is being conducted into developing frameworks for understanding or making sense of interrelationships between these entities in organisations (Midgley and Reynolds 2004; Reynolds 2008; White and Lee 2009). In relation to ethics there has been a concern over challenges and guidance for the practice of OR and systems thinking, the role of 'codes of conducts' and process? (Cordoba 2008; Le Menestrel and Van Wassenhove 2004; Nilsson and Westerberg 1997) (Brocklesbury (forthcoming) White (forthcoming).

Finally, in terms of future developments, there is growing interest in linking environmental and ethical issues to notions of corporate citizenship and social responsibility (Borzaga and Defourny 2001). There is also the problem of under-involvement in representative democracy can be tackled at least in part through participative democratic involvement in organisations. Social enterprises have been mooted to tackle some of these issues and our most entrenched social and environmental challenges in an innovative way. The term social enterprise is, itself, a recent construct (Nyssens et al. 2006). It has now become a widespread part of the lexicon of governmental activity across the UK (Office of the Third Sector, 2005). Social enterprises can come in many shapes and sizes, from community-owned village shops to large development trusts, and in many legal forms, including community interest companies, industrial and provident societies and companies limited by guarantee, among others. The challenge they present is in terms of the fundamental issues of how to create public goods and solutions to social problems in an open market economy. They provide, we believe, opportunities for systems thinking.

3.4 Production, TQM, project management

Managing processes and operations in organizations has been an enduring theme in management/organizational research (Craighead and Meredith 2008; Gupta et al. 2006; Sprague 2007; Voss 2007). Much of the work is founded on the technical principles of Frederick Taylor's "Scientific Management" whose roots go back over a hundred years (Wilson 2003). Today more attention is paid on the organizational and human elements, which are seen as largely reactive to the constraints of the technical system. The management sciences and many early systems thinkers have made a substantial contribution to this field in covering a wide range of subjects, including facilities layout, job design, logistics, inventory control, integrated models of production systems, international operations, advance manufacturing systems, production and employment smoothing, project management, and work measurement (Chopra et al. 2004; Grossler et al. 2008; Voss 1984).

In general, applying systems thinking within the field of operations and production has mainly focused on two intertwining, but sometimes, separate objectives. These are improvements in efficiency and quality. These objectives are linked in that organizations aim at continuous improvement through the elimination of waste, inventories, and labour inefficiencies, all in the service of greater customer satisfaction (Mashayekhi 2000; Murdoch and Esposito 1998; Ormerod 1999b; Senge and Carstedt 2001).

Research on efficiency management generally focuses on the traditional organizational functions and hierarchy, and tend to use techniques from traditional OR. However, in recent years many researchers have shown how systems thinking (in particular SD and SSM) can be the basis for analysing complex organizational operations, for example, in supply chain management (Ayers 1999; Beth et al. 2003; Holweg and Pil 2008; Moon and Kim 2005; Rosen 1998), and project management (Costello et al. 2002; Lyneis and Ford 2007; Mawby and Stupples 2002; Rodrigues and Bowers 1996; Rodrigues and Williams 1998; Winter and Checkland 2003).

By way of an illustration, project management has had considerable attention in the OR literature (Tavares 2002). The basic foundational work had been done before the Second World War., with Gantt (an associate of Taylor) who constructed the Gantt-chart, as a discipline (Wilson 2003). Project Management developed from different fields of application including construction, engineering and defence. The now famous network planning techniques CPA and PERT were developed at the end of the 1950s (Herroelen 2004). The contribution of traditional OR to the subject is mainly concerned with techniques and tools to understand how the transformation involved in fulfilling the task can and should be handled in an efficient way, given the (often limited) resources at hand. Today projects seem to have become increasingly common in all kinds of organizations (Mawby and Stupples 2002). They are increasingly large, complex and constrained and may involve large numbers of interested parties and professional and technical disciplines. Since then, CPA and PERT have appeared in numerous incarnations, all designed to overcome one or more of the practical problems caused by the simplicity of the original techniques (Tavares 2002). There is also the increasing use of computers in daily work-life which has given rise to a new generation of OR devoted to computer applications and expert systems for project planning, control and risk analysis (Kolisch 1999).

Recently, the rationalistic view of project management has come under criticism (Costello, Crawford et al. 2002; Winter 2006; Winter and Checkland 2003). It is assumed that behind the decision to initiate a project there is supposed to be a well thought-out strategy, against which the outcome of the project can be objectively evaluated. However, in practice, projects can be initiated for unclear reasons, undertaken with the process in mind rather than the outcomes, and pursued despite environmental changes which leave the project objectives obsolete or even undesirable. It is being increasingly recognised that decisions and actions are neither necessarily sequential nor mutually coherent. Systems thinkers are contributing to the debate (Achterkamp and Vos 2007; Lyneis and Ford 2007; Mawby and Stupples 2002). In particular, Winter and Checkland (Winter and Checkland 2003), claim that project management in the future will provide a way for organizations to release the innovative forces within themselves rather than to plan. They will encourage the means to enhance participation rather than to control. Systems thinkers are also contributing to theories on learning in projects (Achterkamp and Vos 2007; Howick and Eden 2001; Lyneis and Ford 2007; Mawby and Stupples 2002; Williams 1999a; Williams et al. 2003b), i.e. theories on how project work causes learning at the organizational as well as the individual level, and how this learning can be made useful to the organization in subsequent projects.

With regards to research on quality management, the focus is on how an organization delivers its products and services (Ortner 2000; Sousa and Voss 2001). In this area, the application of the concepts of systems thinking has contributed to the development of approaches such as Total Quality Management (TQM) (Bennett and Kerr 1996; Helzer 1994; Jackson 1995; Mulej and Rebernik 1994; Plenert 1995; Taiwo 2001), Business Process Management (BPR) (Ackermann et al. 1999; Fowler 1998; Ursic et al. 2005), Balanced Score Card (Kaplan and Norton 2007; Kunc 2008) and Enterprise Resource Planning (ERP) (Jacobs and Bendoly 2003). Many of these approaches draw on ideas not only from systems thinking but also from, economics, strategic management (Ackermann, Walls et al. 1999; Evans et al. 1995) and Information Systems (Ackermann, Walls et al. 1999; Ormerod 1999b). Some systems thinkers have concluded that many of the processes are interlinked (Evans, Towill et al. 1995; Leonard 1992; Williams et al. 2003a), and are, therefore, part of the family of systems approaches. While others, particularly from CST, have regarded them as presenting many challenges, (for example see (Jackson 1995)).

Finally, there are many examples in the literature where the applications of TQM/BPR and systems thinking have extended beyond the traditional boundaries of operations and services (Hipkin and De

Cock 2000; Ursic, Anteric et al. 2005). In particular, there are examples of application in areas such as health (Angelis et al. 1998; Ben-Tovim et al. 2007; Benson and Harp 1994; Lane and Husemann 2008b), and in housing (Jackson et al. 2008).

3.4 Agriculture, ecology and the environment

Systems thinking has long been one of the underlying paradigms within these fields, especially ecology. Indeed some of the early systemic concepts were themselves developed by organismic biologists and ecologists in the 1920s (Capra 1997). In more recent times we can discern several distinct although overlapping areas of application and approach.

The first group concerns the use of various quantitative models within especially, farming and agriculture. OR models such as LP have a long history within agriculture and econometric models have also been used. However, it has been recognised that such models tend to be limited to dealing with only a part of the whole picture. The systems approach has then been employed to combine together models representing different parts of the picture in order to deal better with the whole, or to consider the results of particular models within wider contexts and with different stakeholders. For example, Kropff et al (2001) argue that the design of sustainable agro-ecosystems involves the integration of several spatial and temporal levels requiring the combination of extensive data collection, simulation models, expert knowledge, and local knowledge from involved stakeholders. Moreover, each problem will require its own specific research approach. Lauwers et al (1998) were concerned with the problems of manure disposal in Flemish farms. They needed to develop LP models at three different levels – individual farms, local aggregations and the overall region – and then integrate them systemically to deal with the whole system. Meinke et al (2001) survey the practical success of modelling in crop production. They highlight the importance of strong partnerships between all the stakeholders (farmers, researchers and policy makers), the effect of the policy framework, and the actual participation of stakeholders in the modelling process to ensure relevance and commitment. Hjorth (2003) stresses the need for participation and knowledge sharing in programs to alleviate urban poverty.

The second area of work is where more specific systems methodologies are used. This is particularly common in farming systems research (FSR) and natural resource management (NRM). Several authors point specifically to the importance of soft systems thinking and especially SSM. Midmore and Whittaker (2000) surveyed the use of economic models in rural agriculture given criticism that a purely economic rationality tends to lead to increasing mechanization and industrialization, and to worsen resource sustainability. They argued that whilst the modelling techniques themselves were sound they needed to be located within a more systemic framework that recognized a hierarchy of levels of system, each with its own goals, and also the value of using SSM, or other soft methodologies, to ensure participation especially of rural populations. Ison et al (1997) provide a review of the use of systems methodologies within NRM while Bawden (2005), reflecting on 20 years of developments at Hawkesbury Agricultural College in Australia, points to the importance of three waves of systems thinking – hard, soft and critical – in developing a critical systemic discourse necessary to deal with the global challenges that we currently face. Other reviews of this area can be found in Keen (2006) and Stephens (1999).

A third area of activity is applications of complexity theory within agriculture and the environment. Lister (1998) suggests that the field of biodiversity conservation planning has undergone a major shift in moving from being simply a scientific activity to one that is highly politicized and at the same time changing from one based on traditional, rather reductionist assumptions to a post-normal approach based more on complexity and chaos theory, accepting the inevitable linking of observer and observed. Proulx (2007) covers similar ground in respect of ecology more generally using examples of food webs and functional ecology. Plummer and Armitage (2007) address the problem of natural resource management discussed above. They consider an approach called co-management which attempts to integrate ecology, economics and society by involving a range of stakeholders, including land owners and inhabitants, in management. Although heralded as being revolutionary there has been criticism in terms of the outcomes and Plummer and Armistead develop an evaluative framework based on complex adaptive systems. As an example of the use of a specific complexity concept, Vanloqueren and Baret (2008) investigate why new disease-resistant wheat cultivars are not being taken up by farmers and show that there are a range of factors combining together to maintain a pesticide “lock-in”(Arthur 1989).

We should also point to the widespread use of system dynamics as referenced above.

3.5 Medicine and health

Applications in this domain are similar to agriculture in that they involve either the general systems approach or the application of specific methodologies. We will consider three main sub-domains – public health systems, and medicine, hospitals and nursing.

In terms of the general systems approach, as ever the advantages are that it leads to a more inclusive and less reductionist view of a problematic situation, and therefore hopefully more effective and robust solutions. Public health is a typical area in which the prevailing approaches tend to locate problems within the biology and behaviour of the individual person while a systemic approach focuses attention on the wider processes and contexts that shape individual susceptibilities (Leischow and Milstein 2006). Particular studies have looked at adolescent obesity (Pronk and Boucher 1999), cervical cancer (Suba et al. 2006), mental health (McCubbin and Cohen 1999), malaria control (Temel 2005) and maternal health (Parkhurst et al. 2005).

In the more specific area of medicine and hospital management (Ahn 2006), Solberg (2007) has studied diabetes care and Weissman (2005) postoperative care but the most active area is in error prevention and management (Wieman and Wieman 2004). Again this is a classic situation where the reductionist approach would tend to see errors and failures as being one-off events often attributable to an individual’s failure whereas the systems approach sees that although they occur to individuals it is generally the wider process and context that generate them. Anderson and Webster (2001) and Schaubhut and Jones (2000) focus on errors in nurses giving medication, a very common and dangerous occurrence. The traditional, punitive, person-centred approach generally fails to improve performance and also leads to a secretive culture where accidents and mistakes are often hidden, making it even harder to recognize the underlying problems. Consideration has also been given to patient safety (Brand et al. 2007; Womer et al. 2002), inadequate care (Cho 2001) and mismanaged pain (McNeill et al. 2004).

A particular movement that has been influential in the UK National Health Service (NHS) is the “whole systems” approach. This was the result of a 4-year study by the King’s Fund in London (Pratt et al. 1999) into the best ways of developing health services. Most of the traditional research into the NHS had been narrowly focussed and generally involved health professionals. The main emphasis of the whole systems approach, as with all systems approaches, was to take a holistic view of “the system” at whatever level of operation and especially to involve as many stakeholders as possible, particularly patients. A variety of practical research methods were evolved, especially participatory ones, which supplanted, or sometimes complemented, the conventional quantitative ones. Particular applications include practice development and health care governance as part of the UK government's modernisation agenda (McSherry 2004), developing the role of nurses to become overall patient case managers (Kesby 2002) and improving patient access to care according to need (Rogers et al. 1999).

Moving to particular systems methods we can find several applications of system dynamics particularly for problems of patient flow and overload (Brailsford et al. 2004; Lane and Husemann 2008a; Wolstenholme 1999a) and modelling the spread of diseases (Dangerfield 1999; Homer and Hirsch 2006; Perelson 2002). Complexity theory has also been used in the context of health care (Holden 2005; Tan et al. 2005) and disease classification (Loscalzo et al. 2007). Problem structuring methods (PSMs) have also often been applied (Midgley 2006), for example: SSM has been used to improve participation in Health Action Zones (Carr et al. 2006), to evaluate complex interventions (Rose and Haynes 1999) and to help develop simulation models in health care (Kotiadis and Mingers 2006b; Lehaney and Paul 1996c); the Viable Systems Model (VSM) was used to diagnose problems with the organisational structure of an American hospital (Keating 2000); and critical systems thinking was used to examine the politics of waiting lists (Foote et al. 2002).

4. Conclusions

In undertaking this review we have been amazed at the sheer volume of work, especially practical applications, which utilise systems thinking. Although the bibliography is extensive it represents only a fraction of the material that is actually available.

Considering the theoretical developments, we can discern three major phases: the early years, from say 1920s to 1960s, when the fundamental concepts were developed within and across a range of disciplines; the rise of soft systems and other specific methodologies such as VSM, PSMs, and critical systems thinking between 1970 and 1990; and the more recent emergence of chaos and complexity theory. We have seen that while systems thinking can be applied to almost any domain, the individual disciplines have been developing in their own way. Also, while there remain arguments over the relative scope of the applications of systems thinking in a number of these domains, it can be deduced that from the review that the dreams of the pioneers in attempting to forge a transdisciplinary 'Systems Science' is still alive and well.

Indeed, individual disciplines such as cybernetics and GST have had a crucial influence on the birth and development of various modern subjects such as: control theory, computer science, information theory, automata theory, artificial intelligence and artificial neural networks, cognitive science, computer modelling and simulation, dynamical systems, and artificial life (Rudall 2000; Rudall 2002), while practical methodologies such as system dynamics and SSM have been applied to a wide range of domains. (de Water, Schinkel et al. 2007).

Many of the concepts from the systems approaches that are now central to such fields were first explored by systems thinkers during the 1940's, 1950's and 1960's. What was common between the approaches is was that they began with the recognition that all our knowledge of systems, and subsequent interventions, is mediated by our simplified representations—or models—of them, but what is different is that they emphasise different theoretical aspects of systems and systems' behaviour. Whilst there are many branches, their common roots in basic systems concepts mean that there is always the possibility of connecting them together and this is evidenced by the growing interest in combinations of approaches.

In spite of its important role in management thinking generally, the systems approach has not really become established as an autonomous discipline. Its academic practitioners are relatively few and scattered, and there are but a few research departments devoted to the domain, and probably even fewer academic programs. There are many reasons for this, including the intrinsic complexity and abstractness of the subject domain, and the ebbs and flows of management and organisational fashions. Perhaps the most important cause is the difficulty of maintaining the coherence of an interdisciplinary field in the wake of the rapid growth of the more specialised and application-oriented offshoot disciplines, such as computer science, business consultancy, information systems and systems engineering, which tended to drain away interest, funding and practitioners from the more traditional base for systems disciplines.

However, this review highlighted that many of the core ideas of the systems approaches have been assimilated by other disciplines, where they continue to influence further developments, while other principles seem to have been forgotten, only to be periodically rediscovered or reinvented in different domains. Perhaps the most significant recent development is the growth of the complexity thinking. Nonetheless, the number of applications of systems ideas is high and they are making contributions to a wide number of domains, particularly health, production and sustainability. They are also seen to be appropriate in the broad policy and strategy context which are beset with 'wicked problems'. There are also potentially new opportunities, given the context of a global economic downturn and global climate change, for systems approaches which may bring fresh thinking to existing problems and to a future uncertain world. The early pioneers of systems thinking would have relished the challenge of course; they would encourage the new generation to step up to the task.

Information systems	(Garrity 2001; McBride 2005; Mora, Gelman et al. 2007; Porra, Hirschheim et al. 2005; Wainwright and Waring 2004)
Medicine and public health	(McCubbin and Cohen 1999; McSherry 2004; Pronk and Boucher 1999; Wieman and Wieman 2004)
Natural environment	(Hjorth 2003; Kropff, Bouma et al. 2001; Lister 1998; Meinke, Baethgen et al. 2001; Proulx 2007)

Table 1 Applications of the systems approach and complexity

Health	(Espinosa et al. 2008; Espinosa and Walker 2006; Hipel et al. 2007; Ozbolt et al. 2004)
Sustainability	(Chan and Huang 2004; Espinosa, Hamden et al. 2008; Espinosa and Walker 2006; Johannessen and Hauan 1994; Kouloura 2007; Zhong et al. 2006)
Supply chain, production, projects	(Achterbergh et al. 2003; Brewis 2002; Herrmann, Bergmann et al. 2008; Jenner 1998; Leonard 1992; Plenert 1995; Rudall 2000; Shaw et al. 2004)
Other applications	Built Environment (Love and Cooper 2007; Schwaninger and Koerner 2004) Tourism (Lazanski and Kljajic 2006), CSR (Knez-Riedl, Mulej et al. 2006) OD (Klein 2005) e-learning (Kolbe and Nikolopoulos 2007) Finance (Chen 2005) Knowledge Management (Achterbergh and Vriens 2002; Johannessen et al. 2002; Leonard 2000; Yolles and Iles 2006) Negotiation (Solomons and Moscardini 2006)

Table 2 Applications of cybernetics

Health	(Brailsford, Lattimer et al. 2004; Cavana et al. 1999; Dangerfield 1999; Gary and Larsen 2000; Gonzalez-Busto and Garcia 1999; Lane and Husemann 2008a; Lane et al. 2000; Taylor and Dangerfield 2005; van Ackere and Smith 1999; Wolstenholme 1999a)
Environment, agriculture	(Bene and Doyen 2000; Cavana et al. 1996; Janssen 1999; Janssen and De Vries 2000; Noble and Walker 2006; Stave 2002; van Vuuren et al. 1999; Yu et al. 2003; Zhang and Mitsch 2005)
Supply chain, production, projects	(Ackermann, Eden et al. 1997; Dangerfield and Roberts 2000; Fung 1999; Howick and Eden 2001; Kleijnen and Smits 2003; McCray and Clark 1999; Riddalls et al. 2000; Rodrigues and Williams 1998; Spengler and Schroter 2003; Williams, Ackermann et al. 2003b; Williams 1999b; Zhou et al. 2006)
Other applications	(Adamides et al. 2004; Akkermans and van Oorschot 2005; Bajracharya et al. 2000; Cavana et al. 2007; Chen and Jan 2005; Dangerfield and Roberts 2000; Delauzun and Mollona 1999; Jan and Jan 2000; Marquez and Blanchar 2006; Newsome 2008)

Table 3 Applications of system dynamics

Health	(Angelis, Pavlopoulos et al. 1998; Brazier et al. 2008; Fahey et al. 2004; Gregory and Midgley 2000; Hindle et al. 1998; Kotiadis and Mingers 2006a; Lehaney and Paul 1996b; Walsh and Hostick 2005; White 2003)
Environment, agriculture	(Bunch 2003; Hjortso et al. 2005; Kayaga 2008; Marshall and Brown 2003; Pahl-Wostl 2007; Paliwal 2005; Ridley 2005; White and Lee 2009)
Supply chain, production, projects	(Bennett and Kerr 1996; Bunch 2003; Costello, Crawford et al. 2002; Hipkin and De Cock 2000; Horlick-Jones et al. 2000; Ishino and Kijima 2005; Ormerod 1999b; Winter and Checkland 2003)
Other applications	(Brown et al. 2006; Costello, Crawford et al. 2002; den Hengst et al. 2007; Horlick-Jones, Rosenhead et al. 2000; Ormerod 1996b; Ormerod 1999b; Ormerod 2005; Ormerod 1998)

Table 4 Applications of SSM and PSMs

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