MONASH UNIVERSITY
FACULTY OF BUSINESS & ECONOMICS

THE DEBT OF SYSTEMS THEORY TO THERMODYNAMICS

Ian Roos

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ABSTRACT

"Systems theory", is often seen as unifying; spanning the physical, biological, and social sciences. The term theory is perhaps a misnomer in that in general form it is neither testable, falsifiable or predictive. However, most of the theories or laws describing the physical universe use the concept of a system. It can be argued that it fits Kuhn's concept of a paradigm.

"Systems theory" as applied to organisations uses as analogies some of the concepts of thermodynamics, such as open and closed systems, exchange with the surroundings, and entropy. Thermodynamics is concerned with the interchange of energy as either heat or work. It is, therefore, surprising that a concept as difficult to understand as entropy should be borrowed and applied to organisations, but simpler concepts such as work, temperature, heat, and equilibrium ignored. This paper will explore whether there is value in using some of these concepts when describing an organisation as a system.

THE DEBT OF SYSTEMS THEORY TO THERMODYNAMICS

INTRODUCTION

"Systems theory", is often seen as unifying; spanning the physical, biological, and social sciences. Its application to organisations has elements of this unifying approach, although other elements have come from the applications of quantitative methodologies to management, particularly decision making. The term theory is perhaps a misnomer in that in general form it is neither testable, falsifiable or predictive. However, most of the theories or laws describing the physical universe use the concept of a system, and it can be argued that it fits Kuhn's concept of a paradigm, in the sense that is a "disciplinary matrix" shared in common by a community, in this case organisation theorists (Kuhn, 1974). It has been seen as a universal principle connecting all sciences, physical, biological and social - "The skeleton of science" (Boulding, 1956). The term has also been used, almost indiscriminately, to describe a wide variety of approaches to the study of organisations, from biological, psychological, physical, mathematical, information theory and social science backgrounds. The use of the term Ôsystems theory' in these contexts has been reviewed recently (Bahg, 1990)

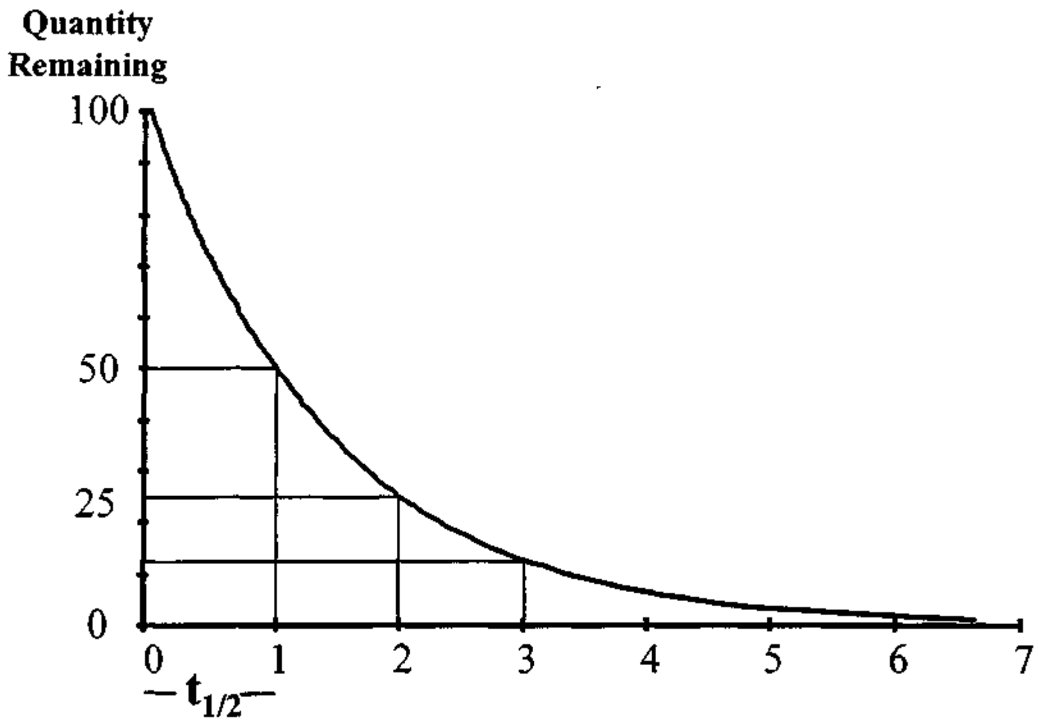
A number of concepts are common to the use of the term system in all these disciplines: an organised collections of entities; a boundary that separates this collection of entities from the surrounding environment; interactions between these entities and the surrounding environment; the entities and the interactions are capable of accomplishing either general purposes or specific goals; the entities themselves, or sub groups of the entities, may be viewed as systems in their own right; and all interactrions are capable of description (Boulding, 1956; Lewis and Randall, 1923; Von Bertalanffy, 1951, Kast and Rozencweig, 1972; Miller and Miller, 1991; Katz and Kahn, 1966). Thus the concept "applies to a cell, a human being, a society, as well as an atom, a planet or a galaxy" (Von Bertalanffy, 1951a). The etymology of the term is from the Greek (Σψστεμα) meaning an organised whole

The quantitative aspects of systems theory arise from viewing the organisation as an adaptive - regulating system and is based on the cybernetic model first promulgated by Weiner (1948). The concept of feedback as a basis for this self-regulation arises from this work, although it is inherent in other description of systems and is perhaps best known through the principle of Le Chatelier; that any system in a dynamic equilibrium if subjected to change will adjust to counter the change and seek to restore the dynamic equilibrium (Miller 1971, Katz and Kahn, 1966). It is predicated in these views that a systems approach is essentially deterministic and that quantitative methods and a scientific approach can be used to identify causal relationships and find optimal solutions. This essentially mechanistic view, when applied to organisations, has led to the applications of analysts, computer modelling and many of the familiar quantitative techniques of management science, such as critical path analysis, linear programming, Monte Carlo simulation and forecasting.

General Systems Theory (Von Bertalanffy, 1951a, 1951b; Hempel, 1951; Bass, 1951; Jonas, 1951; Boulding, 1956), provides the other component of a systems theory approach to organisations. This is essentially a holistic or "organismic" approach, rather than analytical-reductionist, and sought significance in the parallelisms observed in the theoretical development of a number of disciplines. Thus isomorphisms are observed in the mathematical descriptions of different systems: e.g. rate of decay of a radioactive element, first order chemical kinetics, death of bacteria due to sterilants, consumption of an animal with starvation and decrease of a population when death is greater than birth, are all first order processes, that can be described in terms of a constant half life - $t_{1/2}$, (Figure

1). Other isomorphisms are seen in the exponential growth observed in biology and economics, in the same statistical laws applicable to a wide variety of sciences and similar forms of basic equations e.g. the inverse square law observed for gravity, magnetic attraction and the effects of electric charge.[1]

Figure 1. First order decay curve as seen for radioactivity; some chemical kinetics, pharmacology; death of a population due to a toxin.



These isomorphisms suggested that there were underlying common principles, or natural laws, that applied across all sciences. General Systems Theory was to be the new universal basic scientific discipline offering a holistic approach to science as opposed to the existing reductionist approach - "the world shows a structural uniformity manifesting itself by isomorphic traces of order in its different levels or realms" (von Bertalanffy, 1951a.).

Various criticisms have been made of General Systems Theory (e.g. Jonas, 151; Glaser, 1984; Kast and Rosenzweig, 1972), and these essentially are that: it is not predictive in that it can not predict new iso-morphisms, but has to wait for empirical research to establish general laws in a new field then examine these for iso-morphisms; it is not explanatory in that it does not add to the degree of theoretical understanding which is reflected in the ability to predict; it may be an artefact in that our observations may be constrained to seek iso-morphisms, i.e. we may not consider all possible types

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[1] Newton's law of gravity, Coulomb's law of charge and Coulomb's law of magnetic attraction, all have the same general form, $F \propto \frac{m \times m'}{r^2}$ where m and m' are masses, charges or strengths of two magnetic poles, respectively r is the distance and F is the force generated.

of mathematical relationships, only those that provide iso-morphs; the observed "laws" may describe abstract ideality, not reality[2].

Historically, the systems concept predates its application to organisations by several centuries (Lewis and Randall, 1923; Kast and Rosenzweig, 1972), and a brief summary is provided in Table 1.

Table 1: Brief History of the Systems Concept

Philosophical concept from Hegel [1770 - 1831] (Phillips 1971, cited in Kast and Rosenzweig 1972).

Inherent in the mechanistic vs vitalistic debates of late 18th and early 19th centuries

Used by social reformers in late 18th and early 19th century when discussing society, e.g. William Wilberforce [1759 - 1823] (Wilberforce, 1829)

Inherent in the work of early physical scientists: Joseph Black [1728 - 1799], Benjamin Thompson - Count von Rumford [1753 - 1814], James Prescott Joule [1818-1889], Hermann von Helmholtz [1821 - 1894], Rudolf Clausius [1822 - 1888], Sadi Carnot [1837 - 1894], J Wilard Gibbs [1839 - 1903], Le Chatelier [1850 - 1936], et al. (Lewis and Randall, 1923)

Late 1800's biologists beginning to use the term, as in *eco-system*

Theory of *tektology* or organisation science Alexander Bogdanov [1912] foreshadows modern systems theory (Miller, R.,1971 cited in Kast and Rosenzweig 1972).

Biologists in early twentieth century use the concept to describes cells and organisms

Social scientists use the concept from 1930's onwards - Pareto, Parsons, et al.

Management writers use the concept e.g. Chester Barnard 1938

Social sciences in 1950's - Von Bertalanffy, James Miller, et al.

Management writers 1950's - 1970's, Katz and Kahn, Herbert Simons, James March, George Homans, Eric Trist, Fred Emery, et al.

"Systems theory" as applied to organisations uses as analogies some of the concepts of thermodynamics, such as open and closed systems, exchange with the surroundings and entropy. Inherent in much of the writing, however, is the erroneous notion that thermodynamics and other physical laws only describe closed systems, and are insufficient to describe open systems, such as living systems. This has the risk of reviving a new form of "vitalism" (Kast and Rosenzweig, 1972). Thermodynamics is concerned with the interchange of energy as either heat or work. It is, therefore, surprising that a concept as difficult to understand as entropy should be borrowed and applied to organisations, but simpler concepts such as work, temperature, heat, and equilibrium ignored. This paper will explore the implications for organisations of some of the concepts that

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[2] A simplistic isomorphism is frequently seen in the form that the product of two variables is a constant, such as Boyle's Law, Pressure(P) times Volume(V) = k a constant at constant temperature, or the economic law of demand, Price(P) time Demand(D) = c a constant. One problem is that many equations of this form are approximations, describing ideality rather than actuality: thus Boyle's Law describes and 'ideal gas' and for real gases the relationship between Pressure and Volume at constant temperature is better modelled by a virial equation of the form:

$$PV = RT + \frac{BT^2}{V} + \frac{CT^3}{V^2} + \frac{DT^4}{V^3} + ----,$$

where T is the temperature, R the gas constant and B, C, D, etc. are virial constants.

have been borrowed, as well as whether there is value in using some of these other concepts when describing an organisation as a system.

CONCEPTS IN THERMODYNAMICS

Thermodynamics developed as a means of describing physical systems during the ninetheenth century and is primarily concerned with the interchange of energy and its expression as either work or heat. It has been codified in four laws, none of which are stated precisely but all of which are capable of mathematical expression. Inherent in these laws are a number of concepts: Systems, States and Properties; Equilibrium, Stasis and Steady state; Temperature, Work, Heat, Energy; Efficiency, and Change.

The four laws of thermodynamics are , in their chronological order of development (Lewis and Randall, 1923), are stated in Table 2.

Table 2 The Laws of Thermodynamics

FIRST LAW: the concept of Energy

Conservation of energy - Energy cannot be created or destroyed, but is transferred to another form and thus conserved. Work is done in the process. Therefore work, heat and energy are convertible.

SECOND LAW: the concept of Entropy

Heat cannot be completely converted into an equivalent amount of work without causing changes in some part of the system or its surroundings.

A quantity called Entropy is a state function of a system. In a reversible process entropy of the systems and its surroundings remains constant, but in an irreversible process, entropy of the system and its surroundings increases. The entropy of the universe always increases.

ZEROTH LAW: the concept of Equilibrium

If systems A and B are in thermal equilibrium with system C, then A and B are in thermal equilibrium with each other.

THIRD LAW

The entropy of a pure crystalline substance at absolute zero is zero.

In order to understand the dependence of systems theory on concepts developed as part of the physical sciences it is worth considering some of the major concepts.

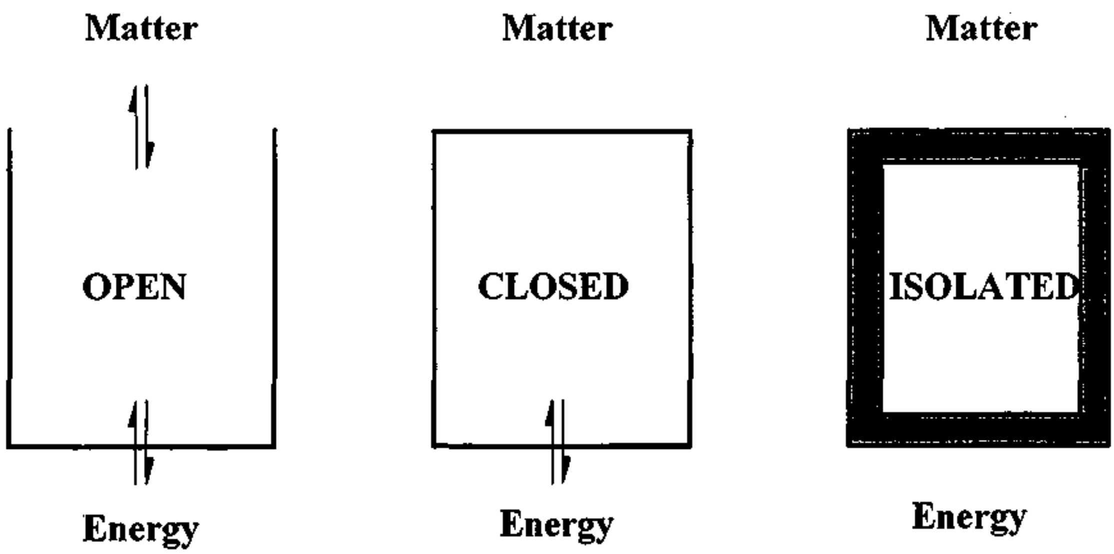
Systems, States and Properties

A system is that part of the objective world under consideration, the boundary of which may be defined either physically or mathematically. Everything of interest is within the boundary; external to the boundary is the 'surroundings'. A state is a description of the system in terms of its properties at any instant of time. The properties describe the present state of the system but do not give a record of its previous history. When a system changes from one state to another the difference in properties depends solely on the states and not on the manner, or pathway, by which the change occurred[3]. A corollary of this is the reproducibility of states, that if the state of a system can be defined by values of its properties, then it is capable of being reproduced.

Types of systems

Thermodynamics has always considered three types of systems, depending on whether matter and energy are exchanged with the surrounding environment, as illustrated in Figure 2.

Figure 2: Types of Thermodynamic Systems



Isolated systems can only be approximated in the real world. The earth may be considered as a closed system; and the universe may be considered as an isolated system

Equilibrium, Stasis and Steady State

All imply that the state of the system does not change with time and are illustrated in Figure 3. With stasis there is no interaction between the components of the system and no exchange with the surrounding environment.

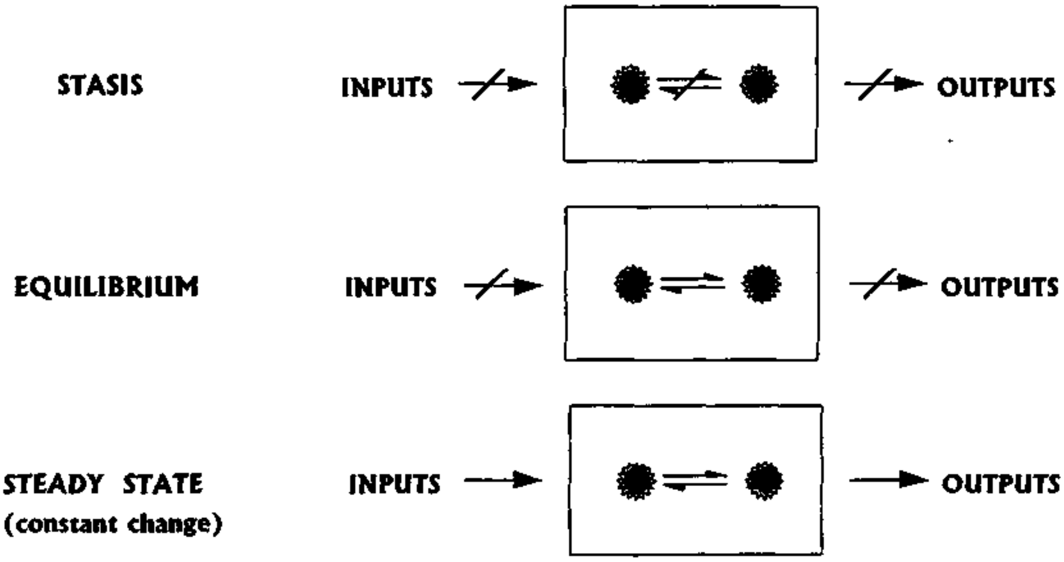
When an equilibrium exists there is no exchange of energy or matter with the surrounding environment, but there are still interactions between the components of the system, hence the term "dynamic equilibrium" is sometimes used (Miller, 1971). The net result of these interactions is, however, no change in the macroscopic state of the system.

A steady state implies an exchange of either matter or energy with the environment, such that there is a balance of inputs, outputs and internal processes. Whilst the system is in a state of continual

[3] A physical system may, as an example, be defined as consisting of a volume of a gas at a certain pressure and temperature. Thus the state of the system is defined by the properties of pressure, temperature and volume. If there is a change in the state of the system e.g. the volume increases, the new state will be described by new values for the properties of pressure, temperature and volume. The gas may have been compressed first and then expanded to achieve the increase in volume, it may have been heated and then cooled to the final temperature, it may simply have been expanded. The difference in the values of pressure, temperature and volume will be the same no matter how the volume change was achieved. The differences in the value of these do not depend on how the change was achieved.

change, the exchange with the surrounding environment continually restores the system so that there appears to be no net change to the system. It is possible to consider a steady state as a dynamic equilibrium in the larger system which contains the system under consideration.

Figure 3: Stasis, Equilibrium and Steady State



Le Chatelier's principle - *If some stress is brought to bear on some system in equilibrium a change occurs, such that the equilibrium is displaced in a direction that tends to relieve the stress* - describes the way that thermodynamic systems at equilibrium react to change.

Temperature, Heat, Work and Energy

Temperature is driving potential that causes heat to flow from one body to another under conditions of unequal hotness and is a manifestation of the average kinetic energy of the particles of the system; the greater the activity of the particles, the greater the temperature. Heat is a form of energy resident in the random motion of the particles which will raise the temperature of the system to which it is added.

Whilst, formally, work is the product of a force acting on a body times the distance through which it moves, it is generally considered as energy directed to produce or accomplish a change in the system that can be detected in the surrounding environment, such as an expansion or contraction. Thus energy becomes the capability of doing work and a system that does not exchange energy with the environment, such as those that are at equilibrium or isolated from their environment, can do no work.

Entropy

There is no clear definition of entropy, but a number of equivalent statements are listed in Table 3.

Table 3: Some Propositions about Entropy

A measure of the amount of unavailable energy in a thermodynamic system.

The difference in energy available, either as heat or work, between a reversible or irreversible process.

A measure of the amount of disorder in a system.

In any spontaneous change in a system entropy increases i.e. it is always increasing in any natural phenomena.

Entropy may be decreased in a system by the inflow of energy, either as heat or work, but the entropy of another system or surroundings must increase, i.e. the entropy of the universe is increasing, or there is a uni-directional flow of all systems towards the final state of equilibrium.

Entropy defines the direction of time, "the arrow of time" (Hawking, 1988) as being in the direction of the expansion of the universe.

Entropy can be expressed in terms of probability - the maximum number of microscopic ways in which the macroscopic state can be expressed "Every system if left to itself will, on the average, change to a condition of maximum probability" (Lewis and Randall, 1923)[4] This sense in which it is used in information theory.

It can be readily seen increase in complexity does not imply an increase in entropy, as complexity does not equate with disorder. The analogy of disorder for entropy is linked to probability, so that a system will spontaneously seek to attain the state of highest thermodynamic probability, that is the state with the highest number of ways of achieving that state, (i.e. the most disordered state).

Efficiency and Reversibility

A reversible process is one conducted infinitesimally slowly, so that at every stage the system is in equilibrium with its surroundings. An infinitesimal change in the external conditions would then bring about a reversal of the process. It is an ideal process that is impossible to achieve practically. The work that can be performed by a system is greater during a reversible process than an irreversible one, and similarly the work that can be obtained from a system, will be greater if the change proceeds by a small number of steps[5].

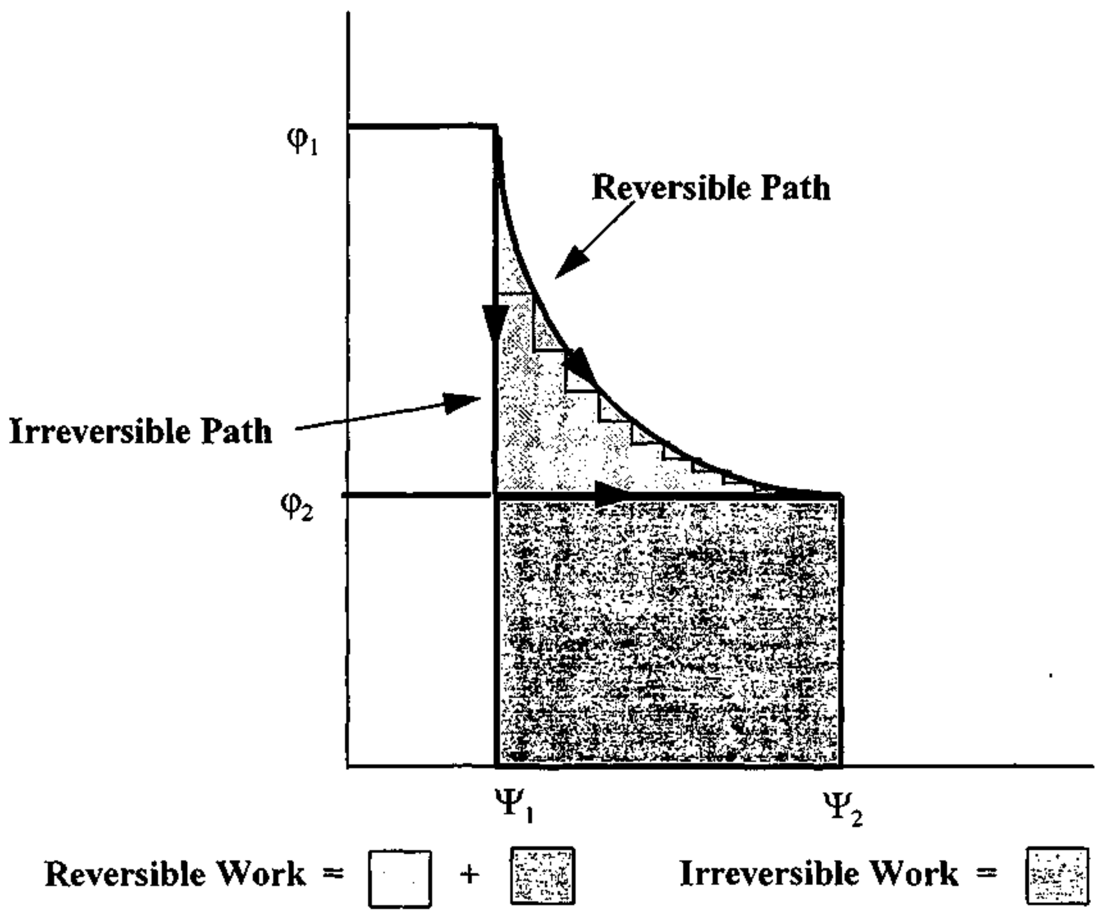
[4] The relationship between entropy and probability is ascribed to Boltzmann The mathematical expression $S = k\ln w$, where S is entropy, w is the probability, and k a constant now known as the Boltzman constant, is inscribed on Boltzman's tomb in Vienna. Boltzman himself ascribed the fundamental idea to Gibbs. (Boltzman, 1912, "Vorlesgungen uber Gastheorie", Liepzig, Barth).

[5] That $w_{rev} > w_{irrev}$ where w is the work done by the system, can readily be demonstrated graphically. A system at state **A**, defined by values of the properties (φ_1, ψ_1), changes to state **C**, (φ_2, ψ_2). This may occur by a reversible path, as shown, where at any point the system is in equilibrium with its surrounding environment. The work that can be performed is shown by the shaded area under the curve and is w_{rev}. If the system changes irreversibly, by going to point **B** (φ_2, ψ_1), then to **C**, the area under the curve, w_{irrev}, is now the lower rectangle and is less than w_{rev}. However, it is also obvious that if the change was to occur by a series of smaller steps as shown, the work that can be performed by the system approaches w_{irrev} as the steps become smaller.

With efficiency there are two concepts: theoretical efficiency, or the fraction of the energy change that can theoretically be converted to work; and practical efficiency, the fraction of the theoretical efficiency that is actually obtained. This means that it is not possible to achieve 100% efficiency, but it is possible to approach the theoretical efficiency..

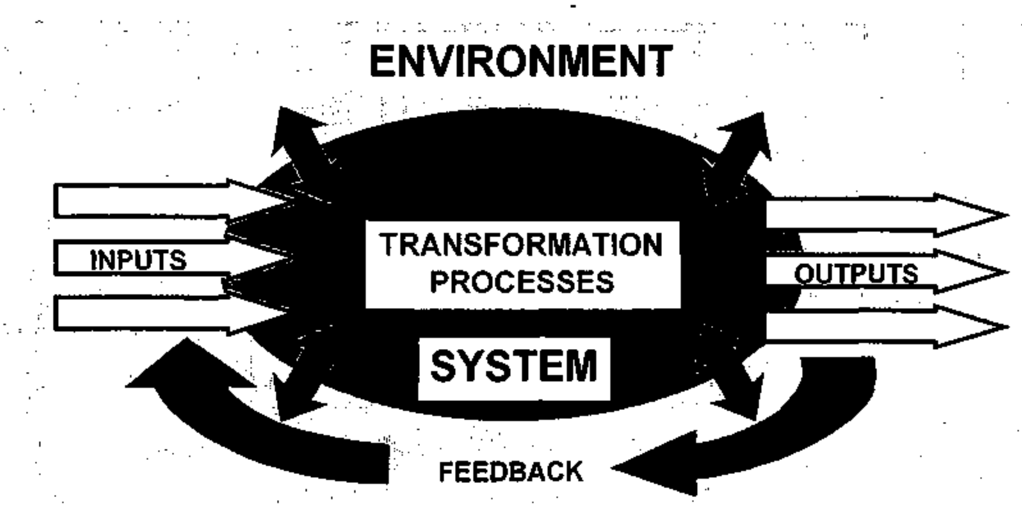
SYSTEMS THEORY CONCEPTS

The basic diagram of an organisational system, Figure 4, found in innumerable management textbooks, distils the essential theoretical perspectives of Weiner's (1948) view of an organisation as an adaptive system. The basic concept being that the system is self regulating through feedback.



The energy change in going form point A to point C, is however, the same. The difference is that for the irreversible path entropy increases whilst for the reversible path entropy remains constant.

Figure 4: The Organisation as an Adaptive System



This in turn links with Katz and Kahn's (1966) application of General Systems Theory to organisations. The key concepts being listed in Table 4 (Von Bertalanffy, 1951b; Kast and Roenzweig,1972; Miller and Miller, 1991)

Table 4: Key Concepts of General Systems Theory

Sub-systems	Systems are composed of interacting parts which are themselves systems.
Holism	The whole is greater than the sum of the parts. The system can only be explained as a totality.
Open Systems View	Systems are either open or closed. Open systems exchange matter, energy and information with environment.
Input -Transformation - Output	The open systems is viewed as being in a dynamic relationship with the environment, receiving inputs and transforming them into outputs.
System Boundaries	Boundaries delineate the system from the environment, but in most systems they are difficult to define.
Negative Entropy	Closed system the change of entropy must always be positive, but in open systems importation of resources from the environment can reverse this and even result in negative entropy change.
Steady State, Equilibrium	Open systems exist not in equilibrium, but in a *quasi-equilibrium* characterised by a balance of inputs and outputs. Closed systems must eventually attain a true equilibrium, with maximum entropy.
Feedback positive or negative	Information concerning outputs is feedback into the system as inputs. In systems theory this is assumed to be negative feedback, that it adjusts the system back towards the steady state.
Hierarchy of Systems	A system is composed of subsystems and in turn is part of a larger system.
Internal Elaboration	Open systems tend to greater differentiation and greater complexity, whereas closed systems move towards disorder and disorganisation as entropy increases.
Multiple goal seeking	Sub-sytems have different objectives, with the result that systems have multiple objectives.
Equifinality	The same end can be achieved with different pathways and from different initial conditions.

A number of problems arise from viewing organisations as systems. These have been summarised by Kast and Rosenzweig (1972) and others (see for example: Glaser, 1984; Ashmos and Huber, 1987; Atkinson and Checkland, 1988).

The analogy between organisation and organism has a long history[6]; and the use of the term "head" as a descriptor for a person in authority is well established. The concept of organisational ecology and the population ecology of organisations (Trist, 1977; Hannan and Freeman, 1977) rests on this. However, this concept may have simply rejected the mechanistic view of organisations and replaced it with one that is equally limited. The danger of assuming that the organisation-organism analogy is better than the organisation-mechanism analogy is to risk proposing a new form of vitalism by not recognising that living organisms obey the laws of physics and chemistry. For example, Katz and Kahn state that physical laws only apply to closed mechanistic systems "The laws of Newtonian Physics are correct generalisations but they are limited to closed systems. They do not apply in the same way to open systems which maintain themselves through constant commerce with their environment."(1966, p273) The organisation-organism analogy is equally as limiting, regardless of whether it is making a comparison of body parts with organisation functions or higher level biological interactions with organisation interactions.

The realisation that the parts of an organism interact to form an organised whole, that is a system, contributes to the organisation-as-organism analogy and assumes that social organisations can be treated in the same manner. There is a fundamental difference however, in that the degree of organisation within a social system is dependent on individual elements that are capable of independent existence, whereas the elements of a biological organism are not capable of independent existence. That something forms an organised whole does not imply that it is an organisation; and in this respect the organisation-organism analogy is as deficient as the organisation-mechanism analogy.

There is also a tendency as part of the organisation-organism analogy to consider that open systems thinking is to be preferred to closed systems thinking. Part of the problem arises from the biological derivation of organisational systems thinking and the concomitant view that physical systems are closed. Katz and Kahn (1966, p 273) give as an example of a closed physical system a bar of iron being heated at one end by a blowtorch. The reality however, is that the system as defined by Katz and Kahn is an open system exchanging both energy and matter with the environment. Part of this confusion arises from the distinction made in the description of physical systems, of isolated, closed and open systems, and the assumption that the word "closed" has the same meaning when used by physical scientists and biological scientists. Kast and Rosenzweig (1972) attempt to resolve this confusion by considering social systems as being either partially open or partially closed. Miller and Miller (1992) suggest that there are hierarchies of systems that can exchange matter, energy, information, people and money. In this hierarchy, it is considered that exchange of people incorporates the exchange matter, energy and information, and that money is a subclass of information.

The assumption that open systems thinking is to be preferred to closed systems thinking is also limiting and does not consider the issue of relevance. As Thompson (1967) and Ashmos and Huber

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[6] There are many examples in Judeao-Graeco-Roman writings to the analogy of organisation as organism. Many of these are moralistic in nature and are used to reinforce the interdependence of individuals in organisations e.g. St Paul's description of the organised church. Many business words, such as corporation, manufacture and management, arise from Latin words for the body or body parts.

(1987) have pointed out, there are times and issues for which closed systems thinking is more appropriate than open systems thinking.

Further difficulties arise in an organisational context with seeking to delineate exactly what is meant by a "system". Whilst it is intuitively easy to conceptualise a system and its boundary, in practice it is difficult, and as Kast and Rosenzweig state "There is a tendency for current writers in organisation theory to accept general systems theory and then to move indiscriminately across systems boundaries and between levels of systems without being very precise" (1972, p.455). This is further complicated by the central concept of systems hierarchy. If all of the elements of a systems are systems themselves, then the system under consideration is also a subsystem of a larger one.[7] It would appear that the concepts of holistic thinking and system hierarchy are mutually exclusive for practical purposes, as bounded rationality prevents consideration of the interconnectedness of all things. Managers within a system are also part of the system, and as such are unable to think in holistic terms. At best they will be able to consider some effects of the immediate supra-system on the organisation, and of the reciprocal effects of the organisation on subsystems.

DISCUSSION

Thermodynamics and Organisation

Thermodynamics have been considered to be the province of physical, mechanistic systems, whilst a living system has been considered to be a better analogy for organisations. It is the argument of this paper tha, as living systems obey the same thermodynamic laws as physical systems, and as system theory is ultimately rational and deterministic, there is value in considering the logical implications ofconsidering an open mechanistic system as an analogy for an organisation.

From a thermodynamic point of view, living systems may be considered as consisting of two types, energy accumulators and energy consumers. Plants are energy accumulators; they photosynthesise and in doing so take low energy and high entropy inputs (carbon dioxide dispersed in the atmosphere, water dispersed in soil, minerals dispersed in soil), and convert these into energy rich, low entropy materials (sugars, and polymeric sugars such as starch and other carbohydrates) by absorbing energy from another system, the sun. Most other organisms are energy consumers, absorbing energy rich, entropy low foods (sugars and carbohydrates) and converting these to energy low, entropy high, waste products, such as carbon dioxide dispersed in the atmosphere. In doing so they may have a smaller number of outputs that are low in entropy. In all of these cases the entropy of all the systems involved has increased, regardless of whether or not there have been local decreases in entropy.

Most organisations can be considered to have aspects of both of these types of living systems. Some organisations, like plants, take in raw materials and convert them to products in which the entropy is lower. They do this by absorbing energy from another system, for example, the electricity grid. Others are like energy consumers in that they take in energy rich raw materials and

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[7] This is reminiscent of Jonathan Swift's epigram

So, naturalists observe, a flea
Hath smaller fleas that on him prey;
And these have smaller fleas to bite 'em,
And so proceed *ad infinitum*. (Swift J, 1733, "On poetry", 1.337)

transform these to thermal and material waste, with a small number of outputs that are low in entropy. However, very few organisations fit this analogy, in that most organisations seek to produce a higher state of order as they transform inputs to outputs. To do this they need to obtain energy, either from energy rich raw materials, from energy conversion processes within subsystems or by energy exchange with the environment. Thus a manufacturing organisation adds value by obtaining energy from another system, or by consuming energy rich raw materials (fossil fuels), whilst it converts other raw materials to products. A social organisation however, may rely on the energy conversion processes of its subsystems (individual humans), who obtain their energy by absorbing energy rich raw materials from the environment and converting them to high entropy waste products. The overall balance, however, is that entropy increases.

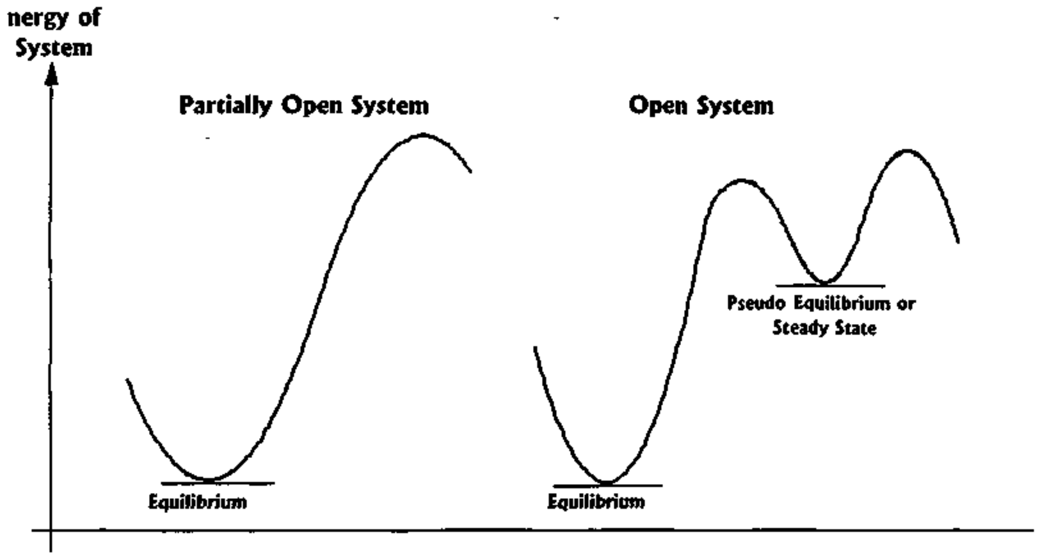
A thermodynamic description of a system is concerned with concepts of available work and efficiency. However, a system is always in a state of activity, unless it is in stasis, even when there is no overall change to the system, such as at equilibrium. Isolated systems can do no work, but activity within the system means that entropy increases, i.e. isolated systems inevitably tend to a state of maximum disorder. Open and closed systems, however, can counter entropy by the influx of energy[8]. This suggests that there may be value for organisation theorists in considering systems where the exchange with the external environment is restricted, or partial, rather than considering only those that have either no exchange, or full exchange, with the environment. The concept of efficiency, in the thermodynamic sense, has usefulness for a description of organisations, in that it recognises that the system puts limits on efficiency, and that some of the energy inputs must be spent on maintenance of the system, and some will be lost as entropy. A further aspect that is valuable is the realisation that a system that is not changing can do no work; if a system is static or at equilibrium, then no external work can be produced

It is perhaps when considering work that the analogy of a thermodynamic system increases in usefulness. Whilst systems theorists have appreciated the principle of equifinality, the implications of this have not always been fully recognised. For a thermodynamic system, energy and entropy are functions of the state of the system, so that changes in these, accompanying a change in the state of the system, are not dependent on how the change was implemented. The amount of work produced by the system during the change is dependent on the pathway chosen. Thus, whilst the same end can be achieved by different pathways, the amount of work that can be performed will be different. The amount of work obtained from a reversible change is always greater than from an irreversible change [$w_{rev} > w_{irrev}$], as the entropy increase in an irreversible process is always greater than that in a reversible process. Whilst it is not possible to achieve a reversible change, the implication is that the amount of work available will be greater if the process of change is conducted in a series of small steps, rather than large steps. The greater the amount of work available, the greater the efficiency of the system. This is reminiscent of the classical organisation writers recommendations for differentiation of work, so that the transformation processes are carried out in a series of small steps. To achieve work implies change in the system; "A system far removed from equilibrium is the one chosen if we wish to harness its processes for the doing of useful work "(Lewis & Randall 1923). As a system moves towards equilibrium energy is converted to work, but as it approaches equilibrium, the available energy decreases. To maximise work a steady state, is preferred, where the system is maintained in a pseudo-equilibrium by new inputs and removal of outputs. This is illustrated in Figure 5, where the lines represents the energy of the system as it moves away from

[8] It has been a long held belief of humans that to produce order requires the intervention of an external agency. This has given rise to much of the ancient middle eastern creation mythology that can be interpreted as "Creation versus Chaos" or the triumph of order over disorder.

the equilibrium position. The term "partially open" has been used in preference to closed system, to indicate that such systems are exchanging energy with their environment. The open systems exchange energy and matter with the environment.

Figure 5: Equilibrium and Steady State.



In the open system the system can be maintained in the pseudo equilibrium state provided inputs approximately match outputs. Figure 5 indicates that there is an energy "hill" to overcome before the system in steady state can approach a true equilibrium. Thus the forces acting on it (Le Chatelier's principle) will seek to restore the pseudo-equilibrium for minor perturbations of the system, but because it is removed from equilibrium the energy available for work is maintained. It also illustrates that when inputs are greater than outputs, resources become available for systems growth, as the system seeks to restore the steady state. Conversely, restoration of the steady state could mean system wastage if outputs are greater than inputs.

Whilst entropy is often equated with disorder, disorder being an analogy for entropy, it is this sense that the term is most frequently used. Energy is required to prevent increase in entropy to prevent a system running down. To create a greater degree of order in the system, to lower the entropy, requires a greater amount of energy than system maintenance. So work is required to prevent disorder as well as creating order. However, complexity does not equal disorder. The more complex the system the more ordered it may be, but highly ordered systems will required more energy to be directed towards system maintenance. Using the probability definition of entropy, organisations with high entropy are those with the maximum number of microscopic ways in which the macroscopic state can be expressed, i.e. the maximum degrees of freedom or the greatest degeneracy of state. This, when an information processing model is considered (Galbraith, 1973), means that there are multiple pathways for information and this is expressed as confusion. Mechanistic systems have lower organisational entropy than organic systems: "The decisive reason for the advance of bureaucratic organisation has always been its purely technical superiority over any other form of organisation" (Weber, in Gerth and Mills, 1977). They have restricted information channels; few degrees of freedom in decision making; considerable differentiation of work; and as a result the interaction between the elements of the system are highly regulated. Organic systems have greater degrees of freedom in decision making; multiple information channels; and there is less regulation of the interactions between elements of the system. Hence there is higher entropy. Organisations with high entropy have lower theoretical efficiency and produce less work output. Thus, when efficiency and productivity are the major features of work organisation there is concentration on mechanistic systems with their greater theoretical efficiency. However, it is a mistake to regard mechanistic systems as closed systems.

The consideration of classification of systems as to whether or not there is exchange with the environment has been well considered for physical systems, but not as well for biological and social systems. There has been some consideration of exchange for social systems by Miller and Miller, (1991, 1992, 1993); and Kast and Rosenzweig (1972). Leaving aside any consideration as to quantity, or quality, of the interaction, it is relatively simple to visualise the possible types of systems. These are listed in Table 5.

Table 5: Allowed combinations of Open/Closed Systems Complexity

Type of System	Properties to Exchange	Number of Allowed Combinations	Combinations,(in order of property)
Atomic	Matter	2	Open/Closed
Physical	Matter, Energy	3	Open/Open: Closed/Open: Closed/Closed
Biological	Matter, Energy, Information	4	Open/Open/Open: Closed/Open/Open: Closed/Closed/Open: Closed/Closed/Closed
Social	Matter, Energy, Information, Individuals	5	Open/Open/Open/Open: Closed/Open/Open/Open: Closed/Closed/Open/Open: Closed/Closed/Closed/Open Closed/Closed/Closed/Closed

It is readily seen that as each level of further interaction with the external environment is added, the level of complexity increases. Each level of system complexity subsumes the previous level which describes the properties of some of the subsystems. Thus, the possibilities for a system that can exchange matter and energy would be : closed to exchange of energy and matter; open to exchange of energy and matter; and closed to the exchange of matter but open to exchange of energy. The remaining possibility, open to the exchange of matter but closed to the exchange of energy, would not be possible as it is property of some subsystems[9]. Similar reasoning has been used to restrict the possibilities to those shown in Table 5. Higher order systems than social systems as proposed by Miller and Miller (1991) have not been included.

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[9] The simplest level, exchange of matter would describe an atomic system, where mass and energy are equivalent forms of matter. The next level of complexity could be envisaged as a molecular or physical system, that could exchange matter and/or energy. Energy may be carried with matter, or it may be exchanged in the form of heat, light, etc. Biological systems can exchange matter, energy and information. Information may be exchanged as matter e.g. specific chemical transmitter/receptors; as energy e.g. radiant energy emitted or received as light or heat; or conveyed or directly as information, such as the specific colours of a flower. Social systems are capable of exchanging individuals, who in the exchange process may carry with them matter, energy and information.

It is obvious that the classification of organisational systems as either open or closed is an over-simplification.

Miller and Friesen (1984) appear to be the only management writers who have borrowed from another major paradigm of the physical sciences, namely quantum mechanics. Quantum mechanics has been used in a very powerful way to describe systems, particularly as quantum processes are indeterministic and unpredictable at the individual level, yet can be used to describe predictable macro systems. Whilst it would be difficult to argue that organisations exhibit quantum effects, there may be value in using some of the concepts arising from a quantum mechanical description of systems.

CONCLUSIONS

Systems theory is essentially deterministic. It assumes rationality and instead of seeking to find a set of principles that can be applied to any organisation, as did the early organisation writers such as Taylor and Fayol, systems theory rests on causality and optimisation. Thus in the subset of systems theory that is sometimes called management systems, the use of computer models, analysts, positive-inductivist logic, and scientific research methodology, explicitly seek to find optimal solutions. Whilst not as explicit, systems theory when applied to organisations as social entities is still implicitly deterministic and assumes that there are causal relationships and optimal solutions.

Systems theory ultimately is an analogy, albeit a useful analogy. The analogy of an organisation as a living system, or organism, may be useful, but it is arguable if it is any more useful than the analogy of an organisation as an open physical system. Perhaps the only major advantage, one not considered by organisation theorists, is the ability of an organism to modify its environment. This is a property of all living systems, that not only do they have to adapt to their environment, but they are able, to a greater or lesser extent, to modify their environment to make it more favourable for their growth and survival.

Analogies form a useful purpose as communication tools, particularly when used to convey new meaning (Ortony, 1975). They do this in three ways: through shared understanding; through imagined understanding; and through new understanding. Shared understanding is when the people involved in the communication have a shared experience that is referred to in the analogy. An imagined understanding is where those communicating are able to share a common experience that may be imaginary for some of the parties. New understanding is where the basis of the analogy has to be explained to the listener who can then translate this to a new area of meaning. In this latter situation the analogy may develop its own meaning that is quite independent of the former. This appears to have happened with systems theory as applied to organisations, where the original meanings have either been misunderstood, or forgotten. It is useful to revisit the original source of the analogy, (i.e. a thermodynamic description of systems), and to appreciate that there is still a richness of meaning that can further enhance our use of the systems analogy for organisations.

> "There is nothing wrong with one discipline borrowing concepts from another discipline; this process has resulted in important theoretical innovations. However, there is a danger that when one area of study borrows key concepts from other disciplines, the concepts become either stereotyped or distorted in the transfer. Also, when concepts are borrowed from other disciplines, they may not be borrowed *in toto*: that is, rather than accepting an entire package - which may include the historical debates surrounding the 'proper' uses of the concepts - people only select aspects of the concepts that suit their interests and thinking

at a particular time. This may result in slanted and biased applications of the concepts or a dilution of the original analytical power" (Meek, 1988)

REFERENCES

Ashmos, D.P., and Huber, G. P., 1987, "The Systems Paradigm in Organisation Theory: Correcting the Record and Suggesting the Future", *Academy of Management Review*, 12(4), 607 - 621.

Atkinson, C.J., and Checkland, P.B., 1988, "Extending the Metaphor "System", *Human Relations*, 41(10), 709 - 725.

Bass, R.E., 1951, "General Systems Theory: A New Approach to the Unity of Science 3. Unity of Nature", *Human Biology*, 23, 323 - 327.

Boulding, K., 1956, "General Systems Theory: The Skeleton of Science", *Management Science,* 2(3), 197 - 208.

Chang-Gen Bahg, 1990, "Major Systems Theories Throughout the World", Behavioural Science, 35, 79 - 107.

Cibora, C., Migliarese, P., and Romana, P., 1984, "A Methodologocal Inquiry of Organisational Noise in Sociotechnical Systems", *Human Relations*, 37(8), 565 - 588

Dunphy, D, and Griffiths, A., 199?, "Theories of Organisation Change as Models for Intervention", Centre for Corporate Change, UNSW.

Galbraith, J., 1973, "Information Processing Model", in Shafritz, J.M., and Ott J.S., 1992, "Classics of Organisation Theory", 3rd edn., Belmont Ca., Wadsworth, pp 308 - 315.

Glaser, S., 1984, "Once More unto the System", *Human Relations,* 37(6), 473 - 490.

Hannan, M.T., and Freeman, J., 1977, "The Population Ecology of Organisations", *American Journal of Sociology*, 82: 929 - 964

Hawking, S.W., 1988, "A Brief History of Time", London, Bantam, pp 153 - 163.

Hempel, C.G., 1951, "General Systems Theory: A New Approach to the Unity of Science 2. General Systems Theory and the Unity of Science", *Human Biology*, 23, 312 - 322.

Jonas, H., 1951, "General Systems Theory: A New Approach to the Unity of Science 4. Comment on General Systems Theory", *Human Biology*, 23, 328 - 335.

Kast, F.R., and Rosenzweig, J.E., 1972, "General Systems Theory: Applications for Organisation and Management", *Academy of Management Journal*, 15, 447 - 465

Katz, D., and Kahn, R.L., 1966, "Organisations and the Systems Concept", in Shafritz, J.M., and Ott J.S., 1992, "Classics of Organisation Theory", 3rd edn., Belmont Ca., Wadsworth, pp 270 - 280.

Kuhn T.S., 1974, "Second Thoughts on Paradigms" in Kuhn, T.S., "The Essential Tension: Selected Studies in Scientific Tradition and Change", Chicago,University of Chicago Press, pp 293 - 319.

Lewis, G.N., and Randall, M., 1923, "Thermodynamics", NewYork, McGraw-Hill.

Meek, V.L., 1988, "Organisation Culture: Origins and weaknesses", *Organization Studies*, 4, 453 - 473.

Miller, G.T., 1971, "Energetics, Kinetics, and Life: an Ecological Approach", Belmont Ca., Wadsworth.

Miller, J.L., and Miller, J.G., 1991, "A Living Systems Analysis of Organisational Pathology", *Behavioural Science*, 36, 239 - 252.

Miller, J.L., and Miller, J.G., 1992, "Greater than the sum of its parts: I. Subsystems that process both matter-Energy and Information", *Behavioural Science*, 37, 3 - 38.

Miller, J.L., and Miller, J.G., 1993, "Greater than the sum of its parts: II. Matter-Energy Processing subsystems", *Behavioural Science*, 38, 151 - 163.

Miller, D., and Freisen, P. H. (1984), *Organisations: a quantum view*, New York, Prentice Hall

Ortony, A.,1975, "Why Metaphors are Necessary and Not Just Nice", *Educational Theory*, 25(1), 45 - 53.

Thompson, J.D., 1967, "Organisations in Action", in Shafritz, J.M., and Ott J.S., 1992, "Classics of Organisation Theory", 3rd edn., Belmont Ca., Wadsworth, pp 281 - 293.

Tracy, L., 1993, "Application of Living systems Theory to the Study of Management and Organisational Behaviour", *Behavioural Science*, 38, 218 - 230.

Trist, E., 1977, "A Concept of Organisational Ecology", *Australian Journal of Management*, 2, 162 - 175

Von Bertalanffy, L., 1951, "General Systems Theory: A New Approach to the Unity of Science 1. Problems of General systems Theory", *Human Biology*, 23, 302 - 312.

Von Bertalanffy, L., 1951, "General Systems Theory: A New Approach to the Unity of Science 5. Conclusion", *Human Biology*, 23, 337 - 361.

Weber, M., in Gerth, H. H. and Mills, C. W., (eds), (1977), *From Max Weber: Essays in Sociology*, London, Routledge and Kegan Paul.

Weiner, N., 1948, *Cybernetics*, Cambridge Ma., MIT Press.

Wilberforce, W., 1829, "A Practical View of the Prevailing Religious System of Professional Christians in the Higher and Middle Classes in this Country, Contrasted with Real Christianity", American Edition.