METAPHOR, MENTAL MODELS AND PARADIGMS IN SUPPLY CHAIN MANAGEMENT: THE IMPLICATIONS OF APPLYING A COMPLEX SYSTEMS VIEW TO UNDERSTANDINGS OF THE CHARACTERISTICS OF SUPPLY CHAINS

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I, Bill Aukett, am currently a procurement manager with the University of Adelaide in South Australia, that is a practitioner and this paper essentially consists of a participant-observer's insights into the things commonly called "supply chains" and the thinking of those who work with and write about supply chains.
Previously I have been a high school English teacher, an internal consultant to the South Australian government secondary education system, an adult education practitioner, and a professional development and organisational development manager.
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ABSTRACT

This paper began life as a sketch for a research proposal to accompany an application for enrolment for a PhD program in an Australian university. The impetus for the paper, which might best be described as pseudo academic, comes from participating with senior supply chain managers from a number of large organisations, some of whom had global supply management responsibilities, in discussions about the impact of the recent global financial crisis on their work and their businesses. This led me to wonder about what it is that supply managers think and believe about the nature of supply chains and what it is that influences their beliefs. This has, in turn, led me to speculate about the language that is used to talk about supply and supply chains as well as the frequently unarticulated assumptions, frames and paradigms that provide a context for supply chain management activities.

INTRODUCTION

The argument that this paper attempts to make is that:

- The language we use not only communicates but also shapes what we perceive.
- From our language come the metaphors, mental models and paradigms that once adopted prescribe the parameters for our actions, choices and decision-making
- Supply systems are not simple but complex, dynamic systems
- Working with and within complex dynamic systems needs a different paradigm than that which applies to simple systems
- Moving from one paradigm to a new one is not evolutionary it requires a clean break
- Paradigms are built from mental models which are in turn constructed by the metaphors that we adopt
- Metaphors are linguistic devices that describe one thing in terms of another well-known thing
- Therefore to shift to a new mental model and to a new paradigm a new metaphor is needed.

The metaphor that is suggested is “Supply Ecology”.

In this paper I will draw on an interest in the ways in which language works and in the ways in which writers and speakers use language to cause their readers to think, feel and act in certain ways, some of which were intended by the author and some of which were not. I will also draw on a further interest in the role of language as both the content of communication and the method of communication in much the same way as the quantum physicists realised that light could be a wave and a particle at the same time. It all depends on what the observer is looking for. This can also be expressed as language being the shaper of experience and the means by which that experience is constrained into a particular view of the world which, in turn, determines how we see the world and how we act in it. Or, to draw again on an analogy from the quantum sciences, how the act of observation influences what is observed.

The paper also draws upon an eclectic range of literature of various sorts – academic research papers, professional articles and books – and from a range of disciplines.

This paper will explore the “supply chain” paradigm and to surface some its characteristics and challenge some of the embedded assumptions. Ultimately, I will be suggesting the need for a paradigm shift in thinking about the interactions and interdependencies involved in the processes of supply.

This paper will argue that a cursory examination of the things that are commonly called supply chains will be enough to demonstrate that they are not chains at all. In fact the metaphor of a "chain" is not only inaccurate but potentially misleading. The paper will suggest that what actually occurs in the procure-supply process is that complex organisations interact in a complex interdependent relationship with other complex organisations, creating what might be best described as an ecology of supply. The use of the "chain" metaphor however constrains our thinking, acting and decision-making in relation to supply management and prevents the use of more appropriate frameworks.

Complexity, a metaphor drawn from mathematical systems science will be used to frame a new paradigm about how the parts of a system and whole systems interact with each other. It is from this frame that a new metaphor for supply activity needs to be drawn so that a new paradigm for action and decision-taking can be established.

DISCUSSION

"A ROSE BY ANY OTHER NAME …"

Wittgenstein noted that, "A proposition like "this chair is brown seems to say something enormously complicated, for if we wanted to express this proposition in such a way that nobody could raise objections to it on the grounds of ambiguity, it would have to be infinitely long," (Wittgenstein, 1961, p. 5e). Metaphors are one of the linguistic devices used to deal with this problem.

The science of linguistics is itself a study in complexity. Saussure (Saussure, 2006) noted the difference between form and meaning and explained that the usefulness of language came from the connection between the two.

Sanders, introducing the writing of Saussure (Saussure, 2006, p. xxi), explains that "meaningful language is produced when the mental representation of the sound sequence and the mental representation of the referent come together in the speaker/hearer's mind". In this coming together, a limited number of sounds (or letters) can generate a potentially infinite number of meanings. That is, the form of a word and its meaning are independent of each other – the meaning that is associated with a form is one that has been agreed by the users group. The word "fish", for example has no connection with the concept of a creature with certain characteristics that happens to swim in water other than consensus agreement that that is what the word should stand for. So "supply" and "chain" have become inextricably

associated with each other, and the value that "supply-chain" has is that the name has by consensus, although not necessarily explicit consensus, come to summarise all of the ideas that are associated with the processes of supply.

In English, grammar dictates that sentences must contain nouns (the names of things) and verbs (the names of actions) but each noun and verb is itself the representation of a concept that is at least complicated. These concepts are modified by things called adjectives and adverbs.

In a recent work, Evans writes, "Many of the concepts we use to apprehend the world are built up in the very process of learning to speak – with the result that our conceptual stock differs markedly with our language background." (Evans, 2010, p. 159) That is, the English language, for its users, shapes their perceptions of the world and is the means by which they give articulation to what they perceive. Or, in quantum terms, what is observed is shaped by the observer. Words, images and ideas are not neutral reflections of reality. They are the means by which we make our reality. There are no sharp distinctions between subjective and objective worlds, with language and reality being part of a life-world in and through which humans and their realities are coproduced (Morgan, 1993, p. 273).

Evans (Evans, 2010, p. 160) also points out that the language specific concepts in speakers' minds are central to ensuring that fellow members of the same language and culture are thinking in the same way. So if someone is part of what might be called the "supply culture", then language specific concepts help to ensure common or agreed understandings about the meanings of terms. Metaphors are a key means by which specific concepts are shaped and shared within culture groups. Metaphors become shorthand for a wide range of concepts or ideas, but they are not precise because the meanings associated with them are dependent on the reader's and the listener's perspectives, experience and predispositions.

Metaphors are so pervasive in our communication with each other that they can become invisible. After a while the concepts and ideas become the sub-surface layer and all that needs to be spoken is the metaphor. For example, many weather related effects are described by metaphors so common, they pass without notice: the wind that *whispers* in the trees; the waves that *lash* the shore; the sun that *beats* down upon the desert. In fact, to use the word "complex" as this paper will propose in relation to the process of supply is to use a metaphor; one drawn from the mathematical sciences.

From a linguistic perspective, metaphors are figures of speech which along with similes, are used to convey meaning that goes beyond the literal meaning of the words. Metaphors are common devices in used

in English to assist in conveying meaning, which relies on the notion of one thing being like another to help audiences comprehend the other. Metaphors depend for their effectiveness on a set of common, culturally-based references to connotations and associations embedded in the metaphor.

METAPHORS AND MENTAL MODELS

Gioia et.al write that the use of metaphor, wherein one concept is understood in terms of another already known concept is pervasive (Gioia, 1994, pp. 364-365). They go on to explain that when people are called upon to enact some change in their existing patterns of thinking and acting, the proposed change must make sense in a way that relates to previous understanding and experience. Symbols and metaphors are key to this process.

Metaphors are also a device for conveying, in a convenient form, a large amount of detail that is built into the mental model or paradigm (Hill, 1995, p. 1064) and they provide a means for individuals and organisations to create and share understanding. Metaphors can aid in sense making (alignment and attunement) in complex environments where not all the detail of the environment is visible (Hill, 1995, p. 1069). They articulate what is important and unimportant depending on underlying values, shared interests, and common understandings. In turn, metaphors contribute to the building of organisational and personal mental models. Mental Models are deeply held internal images of how the world works, images that limit us to familiar ways of thinking and acting (Senge, 1994, p. 174) .

Thus the “chain” metaphor in “supply-chain” provides a basis for a common understanding of “supply-chains” and helps build the parameters within which “supply chain” management occurs. But, as we shall see, supply processes are not chain-like.

Using this framework, we have a metaphor, shaping a mental model, which doesn’t fit that which it purports to describe,

PARADIGMS AND PARADIGM CHANGE

These mental models aggregate into frameworks of both personal and organisational rationalities and belief systems on which formal analyses, policies and procedures are based (Hill, 1995, p. 1059). The shared understandings, contained within mental models, whether explicitly agreed to or as part of the tacit knowledge shared within organisations lead in turn to frames or paradigms. The mental models and subsequent paradigms form the foundations for initiating and organising subsequent actions. Beliefs in mental models and the adoption of paradigms both allow and constrain individuals in

making predictions and making assumptions about the extent to which they can exert control over their environments. Paradigms shape perceptions of reality and form the boundaries within which the options for action are defined and chosen. They are the windows through which the world is viewed.

However, once metaphors are adopted, mental models formed, and paradigms shaped, they also can become the way the world *is*. Unless the paradigms and their associated assumptions are surfaced, they disappear from view and can become both hegemonic and because they are unseeable, unquestionable. As someone once put it, "fish don't know they're swimming in water." The metaphorical concepts that people adopt can be said to shape their reality inasmuch as the metaphors determine the actions we choose and the boundaries (paradigms) for action. Without a paradigm there will be no decision and no action. To make a decision is to identify a paradigm to associate it with (Lissack, 1997, p. 295).

In this context, changing paradigms is not simply about changing words, it is about changing the ways in which someone understands the world. This can be a profound and perhaps traumatic change, which may well be resisted. To stop defensive routines (Argyris, 1990) kicking in, it is necessary to make the paradigm and mental models visible, open to review and open to the possibility of change. If change is required, then what is needed is a new set of mental models or a new paradigm and, to begin this change, a new metaphor is needed.

The usefulness of "paradigms" as an explanatory tool in considering change processes seems to have begun with the publication of Kuhn's *The Structure of Scientific Revolutions* (Kuhn, 1970) originally published in 1962. Kuhn's observations in relation to changes in the operating frameworks for scientific research were adopted by those working in organisational change and development, leadership and management and change management fields. See, for example, Hamel 2007, Vaill 1991, Limerick 1993 and Moss Kanter 1992. They popularised the view of paradigms as a complete and/or alternative view of reality or a way of seeing how schools of thought in the physical sciences could be applied to social organisations and systems.

Writing about change, particularly paradigm change, in the context of science research and teaching, Kuhn argued that people entered a particular branch of scientific endeavour having already adopted a set of fundamentals including law, theory, application, and instrumentation that provide models for a particular coherent tradition of scientific research (Kuhn, 1970, p. 12). This is their paradigm and, having adopted or been inculcated into the paradigm

there is an underpinning set of assumptions for all of their scientific activity that is not challenged and perhaps not even seen. As a result, in terms of scientific investigation, people see what they are looking for and do not look outside the frame, unaware of competing perspectives. Disconfirming evidence is either manipulated so that it fits the existing paradigm or discounted as being irrelevant. Wells (Wells, 2009, p. 22) writes about Kuhn that his insights into paradigms and paradigm shifts have thrown light on the way entrenched mental models shape our individual and collective thinking. He (Wells, 2009, p. 23) also makes the observation that Kuhn also the new paradigm represents a clean break from the old – it is not an evolutionary process – and in making that break it marks the old paradigm as flawed.

An interesting example of discounting of evidence that doesn't fit a paradigm, in a non-scientific context, is described by Festinger etal (Festinger, 2009) on their account of how a doomsday cult survives the failure of its prediction of the end of the world.

THE "SUPPLY – CHAIN" METAPHOR / PARADIGM

The main contention of this paper is that "supply – chain" is an inadequate name for and description of what takes place in the process of supply and that this error may have consequences for those whose role it is to manage supply. These consequences may include lost opportunities for firms to maximise value from their supply management and the possibility of misjudging supply risk. By changing to a new metaphor for the supply processes, new patterns of thinking and acting become possible.

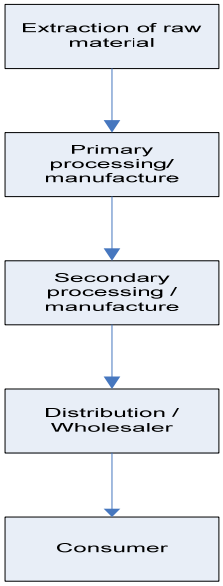
The "chain" metaphor in "supply chain" is saying that the sequence of events involved in the process of supply is like a chain, or, perhaps more precisely, like a "chain of events." Use of the term "supply chain" therefore invokes a series of culturally accepted and understood characteristics such as linear, sequential, and controlled processes.

In one of its White Papers, "The definitions of 'Procurement' and 'Supply Chain Management'" (CIPSA 2007), a professional association explains the terms as follows:

> …the supply chain starts with the extraction of raw material (or origination of raw concepts for services) and each link in the chain processes the material or concept in some way, or supports this processing. The supply chain extends from the raw material or extraction or raw concept origination through many processes to the ultimate sale or delivery to the final consumer whether goods or services. (CIPSA, 2007:6)

The Oxford Dictionary defines “supply chain” as, “the sequence of processes involved in the production and distribution of a commodity” (Pearsall, 1998, p. 1865). The implication of these definitions is that a supply chain looks something like:

Figure 1



The commonly agreed ideas captured in the “chain” metaphor are reflected in this web dictionary definition found through a quick “Google” search:

Chain

–noun

1. a series of objects connected one after the other, usually in the form of a series of metal rings passing through one another, used either for various purposes requiring a flexible tie with high tensile strength, as for hauling, supporting, or confining, or in various ornamental and decorative forms.
2. Often, chains. something that binds or restrains; bond: *the chain of timidity; the chains of loyalty.*
3. chains,
   - *a)* shackles or fetters: *to place a prisoner in chains.*
   - *b)* bondage; servitude: *to live one's life in chains.*
   - c) *Nautical*. (in a sailing vessel) the area outboard at the foot of the shrouds of a mast: the customary position of the leadsman in taking soundings.
   - d) TIRE CHAIN.
4. a series of things connected or following in succession: *a chain of events.*
5. a range of mountains.
6. a number of similar establishments, as banks, theaters, or hotels, under one ownership or management.
7. *Chemistry*. two or more atoms of the same element, usually carbon, attached as in a chain. Compare RING [1] def. 17
8. *Surveying, Civil Engineering*
   - a. a distance-measuring device consisting of a chain of 100 links of equal length, having a total length either of 66 ft. (20 m) (Gunter's chain or surveyor's chain) or of 100 ft. (30 m) (engineer's chain).
   - b. a unit of length equal to either of these.
   - c. a graduated steel tape used for distance measurements. *Abbreviation:* ch
9. *Mathematics*. TOTALLY ORDERED SET.
10. *Football*. a chain 10 yd. (9 m) in length for determining whether a first down has been earned.

–verb (used with object)

11. to fasten or secure with a chain: *to chain a dog to a post.*
12. to confine or restrain: *His work chained him to his desk.*
13. *Surveying*. to measure (a distance on the ground) with a chain or tape.
14. *Computers*. to link (related items, as records in a file or portions of a program) together, esp. so that items can be run in sequence.
15. to make (a chain stitch or series of chain stitches), as in crocheting.

–verb (used without object)

16 to form or make a chain

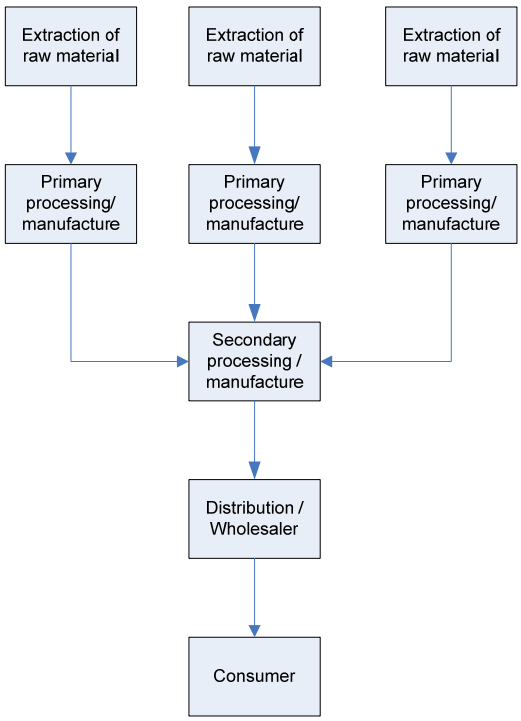
This paper asks the question, “What if supply chains are not simple or even complicated systems but dynamic, complex, adaptive systems?” (Note that in asking this question, “system” refers to the social systems that arise from the interactions of firms and the people in them.) The consequences of recognising supply chains as not being chain-like at all would be to recognise new characteristics of supply processes such as the absence of linear causality and the addition of unpredictability. This, in turn ,would necessitate rethinking approaches to supply management and risk management within supply processes.

MOVING TO COMPLEXITY

The process represented in Figure 1 is of a system that is *simple* (Snowden, 2007, p. 2), in which the relationship between cause and effect is obvious to all, and *best* practice, can be applied (italics original). There is linear, unidirectional and uncomplicated causality. This is the view that might be taken for example, by someone charged with securing electrical energy supply for any medium sized Australian organisation. In this view one approaches an energy retailer, usually through some competitive process such as a request for tender in order to purchase a known quantity of electrical energy for a given period of time. The retailer in turn, sources the energy from a wholesaler / generator via a trading process on the energy spot market or futures market. The generator produces energy by treating coal, oil or natural gas in its generation facility. Once contracts are settled between the parties, the energy is delivered via a transmission network and when an end user flicks a switch, the lights come on.

Most manufactured components are not made from a single raw material but from a combination such as metal and plastic. Consequently even a rudimentary supply chain could be represented as something like Figure 2.

Figure 2



This representation is starting to become *complicated* (Snowden, 2007, p. 3). That is it starts to look like a system in which the relationship between cause and effect requires analysis or some other form of investigation and/or the application of expert knowledge. G*ood* practice can be applied but it still contains assumptions about behaviour characteristic of a *simple* system (italics original). Gattorna's definition (Gattorna, 2006, p. 2), that a "modern supply chain has to embrace any "combination of processes, function, activities, relationships and pathways along which products, services, information, and financial transactions move in and between enterprises" starts to acknowledge complicatedness but stays within the "chain" framework.

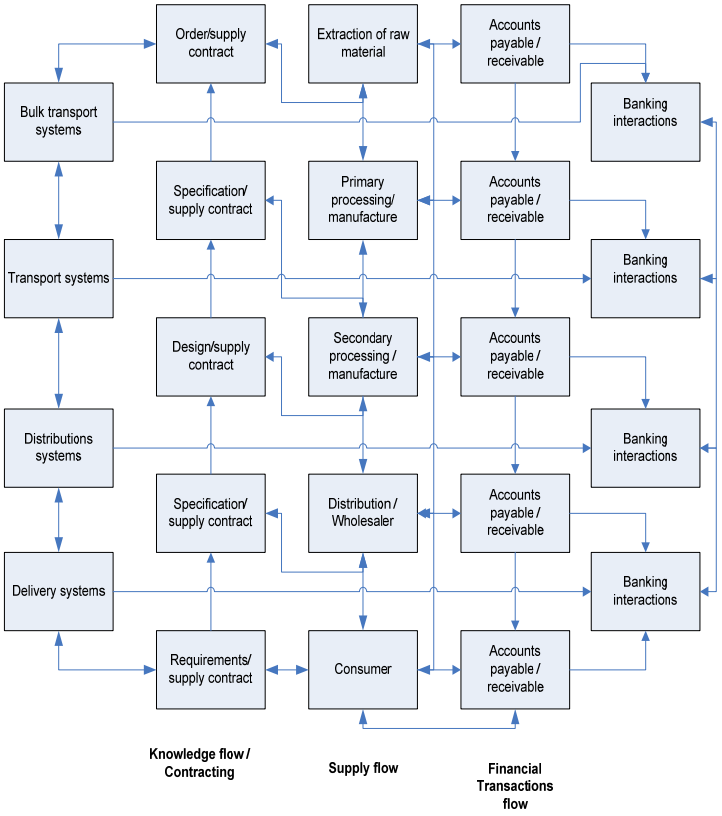
However, to really come to grips with contemporary supply interactions or processes, it is necessary to move into a new paradigm, one that embraces complexity. In the complex paradigm, we can understand why things happen only in retrospect. Instructive patterns, however, can emerge if the leader conducts experiments that are safe to fail. That is why, instead of attempting to impose a course of action, leaders must patiently allow the path forward to reveal itself. They need to probe first, then sense, and then respond (Snowden, 2007, p. 5).

It could be said that in the supply process, interdependence between firms is axiomatic even if the interdependence is limited to the economic sphere – each of the participants depends on the other for economic success. In the framework represented below in Figure 3, it also becomes clear that the supply processes are not contained within the direct or primary participants but there are also links to external participants such as banking services and transport services, not to mention other participants such as packaging suppliers, freight forwarders, customs agents, ports and airport owners. The list could go on.

It is also apparent that in the supply process, the movement of knowledge and information is just as important as the movement of goods and that this movement is not uni-directional.

It should be noted at this point that diagrams such as the one below, are more than representations of complex interactions between benign or inert processes. They also represent the points at which individuals or groups of people interact with each other to facilitate dynamic processes. Taking these characteristics into account, even our initial *simple* supply chain begins to take on the appearance, not of a chain, but of a *complex network* of *interdependent systems* as in Figure 3.

Figure 3



COMPLEXITY AND SUPPLY

Mant (Mant, 1997, pp. 51-63) uses the metaphor of frogs and bicycles to distinguish between simple and complex systems. He writes that a bicycle is a simple system in as much as any reasonably competent person with a few tools can take a bicycle to pieces, clean it and put it back together and it will work precisely in the same way as it has always done. A frog on the other hand can be dissected and eventually all one is left with is a dead frog!

Cilliers (Cilliers, 1998, pp. iix-ix) in the Preface to his book, uses the example of a jumbo jet to further distinguish between a simple (bicycle) system and a complex (frog) system, saying that, “if a system – despite the fact that it may consist of a huge number of components – can be given a complete description in terms of its individual constituents is merely *complicated* (italics original).Things like jumbo jets or computers are complicated. In a *complex* (italics original) system, on the other hand, the interactions among the constituents of the system, and the interaction between the system

and its environment, are of such a nature that the system as a whole cannot be fully understood simply by analysing its components."

These two examples are useful because they not only help to explain the difference between simple, complicated and complex systems, but they also reinforce the usefulness of metaphor as a linguistic device. It is very difficult to write or speak in a way that is absolutely literal, that does not make use of metaphor, symbolism or other figures of speech, just as it is very difficult to talk about supply processes without using "chains".

The theory of complex systems is a mathematical theory (or a body of mathematical theories) (Capra F, 2007, p. 14) and so to use complex and complexity as descriptors of supply systems is indeed to apply a new metaphor. The use of complexity theory metaphors can change the way managers think about the problems they face. Instead of competing in a game or a war, they are trying to find their way on an ever changing, ever turbulent landscape (Lissack, 1997, p. 294).

The seductive aspect of the pervasiveness of "chain" thinking is that in most cases it doesn't seem to do any harm and often assists in the management of supply processes. Eco (Eco, 1999, p. 4) describes this as the force of the false, the phenomenon whereby things that are now acknowledged as being false were, at time in the past, "believed so completely as to subjugate the learned, generate and destroy empires, inspire poets … and drive human beings to heroic sacrifices, intolerance, massacre."

Groups, such as supply professionals, procurement specialists or logistics specialists generate their own specialist language ("jargon" is the pejorative term) with a set of shared and commonly understood meanings. This can be a self-reinforcing loop. Thus, the term "supply chain" has an understood but not always articulated meaning amongst those groups. Ultimately, the un-articulated meaning becomes unchallenged assumptions and, in turn, leads to the perpetuation of a mythology which, while it seems to explain the world can lead to wrong choices.

Reading through professional journals on supply chains reveals a focus on best practice. For example the HBR (Harvard Business Review, 2006) contains a collection of several articles with just such a focus. None of them actually challenges the notion of a "chain". Nelson, Moody and Stegner (Nelson D, 2001), for example, illustrate a position that typifies approaches to managing simple (perhaps "complicated" but nonetheless "simple") systems – benchmarking, which is to take something that appears to work in one setting and replicate it in another and assume that it will work in exactly the same way with the same predicable and controllable outcomes.

That “chain” might be an inappropriate metaphor to use in talking about supply, matters for a number of reasons. One is because of the link between language and behaviour and expectations. Another is because of the cultural values embedded in language. And another is because of the link between organisational change and the limits to change that are imposed as a result of people’s mental models that limit their expectation of possibilities. For example, it is common in many organisations to employ solutions such as “six-sigma” or “lean six-sigma” or “prince 2” to help them address perceived process inefficiencies and project management failings. The use of these techniques supports the mythology that:

- We are dealing with simple systems
- There is nothing wrong with the systems that a bit of fine tuning can’t fix
- In fact we don’t have to change what we do, we only have to do it better or harder

This can lead to the sorts of behaviour that punishes a child for not doing their homework by increasing the homework.

And while, in complex systems there are components that can be rendered amenable to techniques amenable to simple systems, the system as a whole has to be regarded and treated differently. If we are dealing with complex systems then techniques designed for simple systems will not help and may even make things worse in the long term.

Monk (Monk, 2010) uses an anecdote about Wittgenstein to summarise the dilemma: “A student says to Wittgenstein, ‘You know it’s really not surprising that people believed for so long that the sun revolves around the earth, because it looks like that is what happens.’ To which the Philosopher responded, ‘Really? So what would it look like if, actually, the earth revolves around the sun, while turning on its axis?’ The answer, of course, is that it would look the same.”

APPLYING THE COMPLEXITY PARADIGM TO SUPPLY

Johnson sums up Complexity Science as “*the study of the phenomena which emerge from a collection of interacting objects*” (Johnson, 2009 pp 3-4) (italics orginal) and there is an emerging literature on supply networks as complex systems or complex adaptive systems. For example Pathak (Pathak SD, 2007), cites case studies of organisations that are reaping benefits from applying the properties and thinking associated with complex, adaptive systems to supply activities. Choi et al (Choi TY, 2001) call for the adoption by managers of a mental model of a supply network that more accurately reflects its true underlying complexity and dynamism and support the recognition of supply networks as complex adaptive

systems (CAS). Li et al, who describe a supply chain as a network of autonomous or semi-autonomous business entities collectively responsible for procurement, manufacturing and distribution activities which create value for final customers (Li, 2010, p. 310), call for the adoption of the view that the supply processes and activities are complex adaptive supply networks (CASNs).

The word "system" has been widely co-opted for use in many areas of activity in recent years. For example, a customer now goes into a furniture store and instead of a "wardrobe" buys a "clothes storage system". For the purposes of this paper, a system is a collection of interacting objects or agents and a complex system is one in which these objects or agents change their behaviour based on experience (Smith DM, 2010, p. 1). An important difference between systems and chains is that while chains are a function of individual parts, that is, chains of necessity, involve a reductionist approach, systems are wholes and must be dealt with as wholes (Laszlo, 1996, p. 17).

While supply systems might behave, or seem to behave, like simple linear systems, they are, in fact complex with chaotic potential. Chaos theory originates in mathematics where it was discovered that seemingly deterministic equations of motion could lead to unpredictable results and that seemingly linear systems could, as a result of minor variations to the initial conditions, through a process of amplification over time, lead to large scale and unpredictable consequences (Capra F, 2007, p. 12). Known now as the butterfly effect, this provides an interesting commentary on the 2008-9 so-called "Global Financial Crisis" and to what happened in 1996 with the Western Systems Coordinating Council electrical energy transmission network. An electrical energy transmission network is a supply chain for the movement of energy from its source, the generator, to the consumer, the business or household. In systems terms, a transmission network might appear to be a complicated but essentially stable, simple, linear system and that energy is a straightforward commodity. The majority of the western half of the USA from Canada to California is served be a single electrical energy transmission network known as the Western Systems Coordinating Council. In August 1996 this network came crashing down to leave 175 generating units out of service (some requiring days not hours) to restart, 7.5 million people with disrupted power supplies and an estimated cost of $US2bn. This event is entertainingly described by Watts (2003 pp 19-24) at the beginning of his book Six Degrees: The Science of a Connected Age[i]. The detailed report of the Task Force charged with investigating this "disturbance" provides detail of what happened and of the rapidity with which an apparently stable and reliable system failed, how safeguards built into the system to help it cope with stressed

circumstances actually contributed to the widespread failure and how the whole thing was triggered by relatively small and random changes in boundary conditions (operating environment). This behaviour is that of a complex system – it was subject to unpredictable alterations in the boundary conditions and this triggered emergent behaviour that can be described in hindsight in precise detail and the sequences of events and their triggers but it could not have been predicted in any real sense.

Putting this into a supply context, the so called “Bullwhip effect” in which small variations in demand planning are amplified through the whole of the supply networks has been recognized (Lee, 1997).

Although there can be no overarching theory of complexity (Cilliers, 2001), the general characteristics of complex systems have been summed up by a few writers such as Cilliers (Cilliers, 1998, pp. 3-4) and Mitleton-Kelly (Mitleton-Kelly, 2003, pp. 23-53) who both identify 10 characteristics of complex systems:

1 Complex systems consist of a large number of elements.
2 These elements have to interact dynamically. A complex system changes with time.
3 The interaction is rich, i.e. any element in the system influences, and is influenced by, quite a few others.
4 The interactions are non-linear. Non-linearity guarantees that small causes have large results.
5 The interactions usually are fairly short range, i.e. information is received primarily from immediate neighbours. This does not preclude wide-ranging *influence* – since the interaction is rich, the route from one element to any other can usually be covered in a few steps. As a result, the influence gets modulated along the way.
6 Complex systems are recurrent. There are loops in the interactions. The effect of any activity can feed back onto itself, sometimes directly, sometimes after a number of intervening stages. This feedback can be positive or negative.
7 Complex systems are usually open systems, i.e. they interact with their environment. It is often difficult to define the border of a complex system. The scope of the system is usually determined or framed by the purpose of the description, and thus is influenced by the position of the observer.
8 Complex systems operate under conditions far from equilibrium. There has to be a constant flow of energy to maintain the organisation of the system to ensure its survival.

9 Complex systems have a history. Not only do they evolve through time, but their past is co-responsible for their present behaviour.
10 Each element of the system is ignorant of the behaviour of the system as a whole. It responds only to the information available to it locally.

Others have noted additional characteristics such as, “To all intents and purposes, the characteristics of complex wholes remain irreducible to the characteristics or their parts” (Laszlo, 1996, p. 6). This emphasises the contrast between non-systems thinking and management which tend to be reductionist and complex systems thinking. Mitleton-Kelly also points out the connection between complex systems and their environment, writing that complex behaviour arises from the inter-relationship, interaction, and interconnectivity of elements within a system and between a system and its environment (Mitleton-Kelly, 2003, p. 5). Juarrero argues that an inter-level causality place when parts interact to produce wholes, the resulting distributed wholes in turn affecting the behaviour of their parts. Interactions among certain dynamical processes can lead to system-level organisation with new properties at are not the simple sum of the components that constitute the higher level (Juarrero, 2002, pp. 5-6). Artigiani adds that the key concepts here seem to be about “series”, “sequence” and “links” with connotations of “control”, “confine” and “order”. But sequence is not causation (Artigiani, 2007). He also writes that in non-linear systems the effect of the non-linearity is to undermine certainties (Artigiani, 2004). The implications of this for those who would describe themselves as “supply chain managers” are to take away predictability and to open up the possibility of supply systems behaving in unpredictable ways. The myth of certain knowledge must give way to discontinuity and random phase changes (Artigiani, 2004, p. 595)

CONCLUSION

SO WHAT?

Given the demonstrably complex nature of the supply process, the supply ecology, simply extrapolating (Aaltonen, 2007) from the past to the future using linear causality is not going to work. Scenario planning, using a limited number of extrapolations is not going to work. The story of complexity is the story of a different causality. We have seen that when it is unpacked the “supply map” is one of interdependent networks connected in complex and dynamic ways, linking into and from a range of different internal and external environments.

Described this way, supply processes start to look like ecosystems and this paper has suggested the adoption of the metaphor, “supply ecology” to replace “supply-chain”.

The theories of complexity provide a conceptual framework (Mitleton-Kelly, 2003, p. 4) which is different from that encapsulated in the “chain” metaphor but it may be the case that at some surface level nothing changes with the adoption of a new paradigm – the appearance of things stays the same.

Monk (Monk, 2010) uses an anecdote about Wittgenstein to summarise the problem of things looking the same no matter what paradigm is used: “A student says to Wittgenstein, ‘You know it’s really not surprising that people believed for so long that the sun revolves around the earth, because it looks like that is what happens.’ To which the Philosopher responded, ‘Really? So what would it look like if, actually, the earth revolves around the sun, while turning on its axis?’ The answer, of course, is that it would look the same.” So why should the adoption of a new metaphor for supply management activity matter?

The answer is that new paradigms involve new thinking and it is the new thinking that may lead to new strategies for managing complexity that could lead to improved supply outcomes for organisations.

As we have seen, supply takes places in a complex environment and involves complex, dynamic systems. One of the features of complex systems is that causality is not linear and often past behaviours are not good guides to future outcomes. Most procurement and supply activity, however, is actually future orientated. A contract is written to facilitate something that will happen at some time in the future and in the case, for example, of things like defence capital equipment procurement, contracts are written for something that may have to have a thirty-year useful life. Supply and procurement managers are trying to determine outcomes that are, as complexity science tells us, unpredictable and perhaps unknowable.

One of the problems with even apparently simple, stable systems is that they often exist on the edge of chaos and it can only take relatively small changes to the boundary systems to make them highly unstable. This paper has already mentioned the power disruption to the Western Coordinating Council electricity transmission network in August 1996 as an example. More recently we have seen global airline schedules severely disrupted by a failure in baggage handling systems. In both cases the disruption was unpredictable and causality was established in hindsight.

Choi et al (Choi TY, 2001, p. 352) quote this comment made by a manager of a leading automobile maker who has experiences supply complexity: “A few years ago, our engineers mapped a supply chain of a small assembly [by] tracing it all the way back to the mine. From that exercise, we demonstrated the benefits of supply chain management, and we set out to manage the supply chain as a system. Frankly, we have not been able to do it. The problem was, as soon as we came up with a strategy for managing the chain, the chain changed on us—we got new suppliers and new relationship configurations. It took a lot of effort to map one supply chain, and we could not possibly map it every time something changed.” Choi et al conclude that, “Clearly, ‘good intention’ is not enough. Managers must possess a mental model of a SN that more accurately reflects its true underlying complexity and dynamism.

This account of a manager’s experience is very similar to Moss Kanter’s (Moss Kanter, 1989, p. 19) comments that, “to some companies the contest in which they are now entered seems increasingly less like baseball or other traditional games and more like the croquet game in *Alice in Wonderland* - a game that compels the player to deal with constant change. In that fictional game, nothing remains stable for very long, because everything is alive and changing around the player- an all-too-real condition for many managers. The mallet Alice uses is a Flamingo, which tends to lift its head and face in another direction just as Alice tries to hit the ball. The ball, in turn, is a hedgehog, another creature with a mind of its own. Instead of lying there waiting for Alice to hit it, the hedgehog unrolls, gets up, moves to another part of the court, and sits down again. The wickets are card soldiers, ordered around by the Queen of Hearts, who changes the structure of the game seemingly at whim by barking out an order to the wickets to reposition

Many employees in many organisations, anecdotally at least, seem to experience the world in ways similar to the above. The challenge is to find ways of enabling supply managers to operate more successfully than many of them do already.

Adopting a paradigm for supply management that includes complex adaptive systems view of procure - supply processes will, for example, lead to new insights in relation to identifying and managing supply risk. Systems modelling, for example, which recognises the need to look at risk from multiple perspectives can lead to improved risk assessment and management (Haimes, 2008).

One possibility is that what Weick (Weick KE, 1993) observes in his research and calls a collective mind, can be developed amongst supply managers and their supply teams and this will in turn lead to greater capacity to manage the unexpected which is characteristic of

complex systems. Artigiani (Artigiani, 2007) uses naval history to illustrate how success can come from the skills to respond flexibly and quickly to the unexpected rather than defeat that can come from rigid adherence to rules which like best practice cannot cope with the new.

Perhaps what is needed is to legitimise judgement and intuition as tools for managing in a complex supply environment. What we call intuition seems, at least partially, to be a response to the familiarity of paradigms within which we habitually operate. Many effects of the dynamic feedback loops in complex systems can lead to what appear to be counter-intuitive outcomes. That is, outcomes that are not what our habitual paradigms would lead us to expect.

In the supply ecology paradigm, where ecosystems are seen as complex, self-organising, open systems out of which integrity, flourishing, resilience, or adaptability emerge as the properties off the wholes (Ehrenfeld, 2004, p. 144), Goleman (Goleman, 2009, p. 44), might suggest ecological intelligence involves recognizing and understanding the countless ways man-made and natural systems interact with each other as a useful direction.

Some writers are now proposing “Systems Intelligence” as a means of developing attributes helpful in working with complex systems. Saarinen and Hamalainen (Saarinen, 2004, p. 1) describe systems intelligence as intelligent behaviour in the context of complex systems involving interaction and feedback and write that someone acting with systems intelligence engages successfully and productively with the holistic feedback mechanisms of the environment, and perceives themselves to be part of a whole as well as influencing the whole. By observing her own interdependence in a feedback intensive environment, she is able to act intelligently. Saarinen and Hamalainen (Saarinen, 2004, pp. 2-3) go on to list 19 key ideas of systems intelligence and go on to describe the sorts of mental models that they see as being required in the acquisition of systems intelligence.

Hamalainen and Saarinen (Hamalainen, 2006, p. 19) in another article describe systems intelligence as being able to account for an individual’s non-rational, non-propositional and non-cognitive capabilities, such as instinctual awareness, touch, “feel” and sensibilities at large, as capabilities that relate the subject intelligently to a system. So from a supply-ecology perspective, systems intelligence can support different perspectives on supply processes and systems. They also suggest (Hamalainen, 2006, p. 22) that systems intelligence can be leveraged to achieve systemic interventions.

Meadows (Meadows, 1997) identifies, in rank order of the potential power of the intervention, lists 10 places to intervene in a system and in her discussion suggests how they might be leveraged.

Achieving paradigm change is at the top of the list.

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