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Theory of Complexity: Guidelines for Strategic Management and Supply Management

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ABSTRACT

This chapter continues the theme of this part of the book of observing strategic supply management through different theoretical lenses; here the theory of complexity is used to provide guidance for strategic management and supply management. First the principles of complexity theory are discussed, then applied to strategic management; seven principles of the theory of complexity are developed into seven principles of management of complexity. Finally these principles are applied to complex supply management. In conditions of high complexity, the supply network has to adapt and create new opportunities, finding a dynamic equilibrium between control and emergence. These principles of complex supply management should be considered as general guidelines that have to be adapted and customized for every organization. Conclusions and managerial recommendations for new ways of thinking about strategic supply management are drawn.

KEYWORDS

Complexity theory, complex adaptive systems, complex supply management

INTRODUCTION – THEORY OF COMPLEXITY AND COMPLEX ADAPTIVE SYSTEMS

Supply management is harnessed in a web of complexity in such a way that it is necessary to talk about the supply network as a complex adaptive system. Complex adaptive systems (CAS) are researched by the interdisciplinary body of studies known as 'theory of complexity'. In this chapter we suggest a theoretical framework, divided from a logical point of view in three parts:

- identification of the principles of the theory of complexity;
- application of the identified principles to strategic management;
- application of the identified principles to supply management in particular.

The chapter focusses on the principles required to face complexity, fundamental for supply networks to tackle and succeed in addressing new challenges. The aims of the chapter are both to provide new insights to the strategic management of supply, and provide managerial recommendations for new ways of thinking about strategic supply management.

The theory of complexity is a coherent body of knowledge considered nowadays by many scholars to be a multidisciplinary science that studies complex systems (Morin, 1990; Battram, 1999). It takes into consideration elements coming from very different disciplines, such as systems theory, cybernetics, meteorology, chaos theory, artificial intelligence (AI), artificial life, cognitive sciences, computer science, ecology, economy, evolution studies, genetics, game theory, immunology, linguistics, philosophy, social sciences, and management.

Complex systems are characterized by numerous and different elements and numerous, non-linear connections (De Toni and Comello, 2010); moreover CAS, which are complex living systems, are characterized by the capacity of adaptation (Holland, 2002). A CAS may therefore be described as an aggregate of agents and connections, organized to grant adaptation; according to Holland (1995), a CAS is a system that emerges over time into a coherent form, and adapts and organizes itself without any singular entity deliberately managing or controling it. This capacity of adaptation is reached through elaboration of information and model building: the most important aim for the elements of the system is adaptation, and to reach their aim they continuously look for new ways of doing things and learning. CAS therefore continuously exchange matter, energy and information with the environment (Prigogine and Stengers, 1979), creating extremely dynamic systems where small changes can generate unimaginable consequences (Axelrod and Cohen, 1999), also commonly known as the butterfly effect. They place themselves between simplicity – too close to the immobility of a mechanism – and uncheckability – too close to loss of control (Battram, 1999). CAS are everywhere: animals, human beings, groups, populations, organizations, markets, the World Wide Web, and so on.

A supply network is a complex adaptive system too, characterized by material flow and knowledge flow (Choi et al., 2001): managers have struggled with the dynamic and complex nature of supply networks and the inevitable lack of prediction and control. They have to accept the challenge of complexity, which provides us with questions rather than answers and tries to answer questions apparently without a possible answer.

Supply management practitioners have begun in the last decade to consider theory of complexity and its insights. A milestone is the paper by Choi et al. (2001). One of the most important schools of thinking considering the theory of complexity within supply management is the IMP (industrial marketing and purchasing) group. The research of the IMP group is based on the idea that business is not an isolated activity that occurs within independent organizations, but that it consists of interaction between interdependent companies, whether as customers, suppliers, development partners, facilitators, or competitors. It uses an interaction approach. The theory of complexity, trying to explain complex phenomena, can help our understanding of the dynamics that happen within and between organizations. By considering what happens in nature as a sort of 'best practice', it can give to managers and entrepreneurs some guidelines to govern the ever-growing complex situations they face.

PRINCIPLES OF THE THEORY OF COMPLEXITY

Since the theory of complexity is a multidisciplinary field of study, literary contributions are numerous and heterogeneous. In this first part of the chapter we try to rationalize this vast field by identifying seven principles of the theory of complexity (see Table 13.1), which explain the core dynamics of CAS. It is important for supply management practitioners to understand them in order to give new insights to the discipline and new research directions. Supply management in particular will be considered at the end of the chapter, but the previous parts are necessary building blocks that provide the fundamental concepts from the theory of complexity. Each of the following paragraphs will take into consideration one of the seven principles of complexity.

Table 13.1 Principles of the theory of complexity

1	Auto-organization
2	Edge of chaos
3	Hologrammatic principle
4	Impossibility to forecast
5	Power of connections
6	Circular causality
7	Try and learn

Auto-organization

The theory of complexity studies systems that are open from a thermodynamic point of view, not closed as the ones studied by the second principle of thermodynamics. In these open systems, thanks to the continuous flow of matter, energy and information with the environment, opposed to the tendency to degradation (entropy) there's a tendency to organization (neghentropy) (Prigogine and Stengers, 1979). This is called 'auto-organization': '[...] the tendency of an open system to generate new structures and shapes starting from internal dynamics. The organizational design is not imposed top-down or from outside, but emerges from the interactions of the agents in the system' (Olson and Eoyang, 2001, p. 10). This is in stark contrast to top-down designed organizations or traditional hierarchical supply chains. One of the best and most general characterizations of auto-organization is the one proposed by the systems thinking expert Gharajedaghi (1999). In his opinion, in every field – natural, social, organizational – auto-organization can be considered as a process where extremely differentiated elements reach a greater integration. Flocking birds and ants are classic examples of auto-organization.

Complexity scholars state that auto-organization is a process of emergence supported by positive feedback, cooperation, and competition. Emergent phenomena seem to have a life of their own with their own rules, laws, and possibilities. Chance, order, disorder, and positive feedback are all elements that develop into emergence (Waldrop, 1992). To have auto-organization, single elements must at the same time cooperate and compete – cooperate to join forces and compete to achieve the best results (Waldrop, 1992; Olson and Eoyang, 2001). Nobel Prize-winning Philip Anderson (Waldrop, 1992, p. 84) declared: 'Emergence, in all its infinite variety, is the most enchanting mystery in science'.

Edge of chaos

Evolution takes CAS to that area between order and disorder termed, by complexity scholars, the 'edge of chaos' (Waldrop, 1992). The edge of chaos is viewed as the only place where life can take place. Too much order causes death by ossification, too much disorder causes death by disintegration. According to Cohen (1997, p. 69): 'At the edge of chaos, the borders of change continuously flow between a stagnant status quo and the anarchy of endless destruction'. Therefore the edge of chaos is a dangerous place to visit. It is neither order nor disorder, but rather lies between order and disorder. It is a place of creation, but it can also be a place of destruction.

From a mathematical point of view, as demonstrated by Danish physicist Per Bak and his collaborators, a system can be considered at the edge of chaos if it follows a power law. This can be considered as a sort of law of change for complex systems: they continuously change to adapt to the environment through a non-stop flow of matter, energy and information. These changes can be smaller

or larger, possibly many small changes (continuous improvement) or a few larger, more substantial disruptions (radical innovation). This law was found to be true for many different phenomena, including solar activity, light from galaxies, flow of electric current through a resistor, flow of water in a river, and telluric movements. This principle invites us to accept the contemporary presence of contrasting concepts (Morin, 1990), such as order and disorder, creation and destruction, life and death. We should move from 'or' culture to 'and' culture (Amietta, 1991); things don't exclude themselves, annul each other, or neutralize, but rather they coexist and aggregate, live together, integrate, recall, and achieve some form of dynamic equilibrium. Moreover, we should accept disorder as necessary for creation (Morin, 1990). Disorder is everywhere (Bohm, 1957); – in all living systems (Morin, 1990), in our mind (De Angelis, 1996), in every organization (Quattrocchi, 1984), and throughout history (Waldrop, 1992).

Hologrammatic principle

System and environment are tightly linked; there's a mutual dependence due to material, energetic, and informational flow. Therefore, a CAS both reacts to, and creates its own environment, because 'there is feedback among the systems in terms of competition or co-operation and utilization of the same limited resources' (Goldstein, in Zimmerman et al., 1998). The borders between system and environment become faint, sometimes non-existent, or arbitrary (Varela, 1979; Gharajedaghi, 1999). To describe this tight relationship, complexity scholars utilize what they term the 'hologrammatic principle' (Morin, 1990). The term 'hologram' was coined in 1947 by Dennis Gábor, who combined the Greek words holos (whole) and gramma (transfer); thus, a hologram consists of the transfer of the whole into its parts. Gabor applied the hologrammatic principle in physics: in a physical hologram, the smallest point of the image includes all the information of the represented object, as in fractals (Mandelbrot, 1977).

The hologrammatic principle takes into consideration this fundamental conept about physical hologram and maintains that in complex systems the part is in the whole, and the whole is in the part (Morin, 1990). Typical examples are stem cells within the human body. They are parts of the body and reside within the whole body, but at the same time include information about the whole body within themselves. Pribram (1985) used the hologrammatic principle for the repesentation of the brain; even memory and language are organized according to the hologrammatic principle (De Angelis, 1996). Moreover, the 'Santiago theory', developed by Chilean scientists Maturana and Varela between the end of the 1980s and the beginning of the 1990s, utilized a hologrammatic logic to represent the way in which we understand and give sense to our external reality through mental schema.

Impossibility to forecast

The future is not predictable. In a complex system it is often true that the only way to predict how the system will behave in the future is to wait literally for the future to unfold (Choi et al., 2001). CAS evolve through bifurcations (Prigogine and Stengers, 1979), that is through periods of continuity followed by points of discontinuity; when they reach these points, their evolution is unpredictable, and could follow a number of different ways, or bifurcations. However, unlike chaotic systems, complex systems are not totally unpredictable. Mathematician Ben Geoertzel (Lindberg et al., 1998) distinguishes between the impossibility to forecast state and structure; complex systems are unpredictable in their state, but not in their structure. For example, the specific state of weather conditions is not predictable; it is impossible to predict what the weather will be like in the coming weeks and months. Notwithstanding this, the structure is not unpredictable; in fact there are some regular patterns that make it possible to predict, for example, the average climate of the next few months.

It is apparent that systems will tend to be involved in certain prototypical ways and, thus, our predictive capacity, although limited to the exact prediction at a future point in time, can benefit from the knowledge of these patterns (Choi et al., 2001). Complexity theory takes into consideration, between spaces of predictability and unpredictability, the space of possibilities (Battram, 1999), where everything is possible within a certain structure. In a complex environment, where there is space for unpredictability and possibilities, predicting and imagining how to behave in the future may become dangerous activities and we have to recognize and pay attention to weak signals (Harris and Zeisler, 2002). We have to evolve in complex, 'rugged landscapes' (Kauffman, 1995). Optimization can be an illusion; as one sits on the top of what appears to be a mountain peak, it may transpire to be merely a small hill. Additionally, everything is changing in a dynamic fashion, and so the landscape is dynamic; therefore, landscapes can be both rugged and changing (Choi at al., 2001).

Power of connections

The Italian philosopher Quattrocchi (1984, p. 36) asserts that 'What is raised as scientific object [by the theory of complexity] is not the thing, but the set of relationships that a complexity point of view finds out beyond the thing/element'. Complexity scholars state that the whole is more than the sum of the parts (Waldrop, 1992), and the added value is given by connections. This fact has been demonstrated by different types of simulations, including neural nets, classifying systems, and Boolean networks. The basic idea of simulations that demonstrate the power of connections is to represent a population of interactive agents as a net of connected knots. With reference to these simulations, it is possible to talk about 'connectionist models'. The behavior of supply networks can also be simulated using these models.

Thanks to one of these simulations, American scientist Stuart Kauffman was able to demonstrate the results already reached by Prigogine (Waldrop, 1992). In fact he demonstrated that just by increasing the number of connections between knots, the system goes through a transition phase, from order to the edge of chaos and, finally, to disorder (Battram, 1999). This happens just by altering the number of connections, therefore it is meaningful to adopt the slogan the 'power of connections'. Moreover, it is possible to say that all things and individuals of the world are parts of a vast non-linear net made of incentives, constraints, and connections. The smallest change of any part causes disruption to the other parts. Capra refers to this phenomenon as the web of life (1996).

Circular causality

Linear causality is one of the most important philosophical concepts within the occidental world. It was considered by Aristotle, who identified efficient, material, formal, and final cause. Classic science singled out a linear relationship between cause and effect; a particular fact causes a particular effect, proportional to the cause. The relationships between cause and effect have been examined and considered by many other philosophers, notably David Hume (1711–1776) and Immanuel Kant (1724–1804).

Whilst the attribution of a certain effect to a certain cause might be desirable to establish, this attempted connection often is in vain, as many twentieth century thinkers understood, thereby shifting interest from linear causality to circular causality. The concept of circular causality was first examined by scientific researchers from the field of cybernetics, notably within studies by Norbert Wiener. Circularity developed to become one of the fundamental concepts of the theory of complexity. Cause acts on effect, which feeds back on cause. Virtuous and vicious circles arise. These circles can even be linked together and originate the complex web of life.

Try and learn

The development from classic Darwinian evolution to complex evolution caused a great shift in the way scholars have looked at learning. Evolution and learning are, in fact, tightly linked. 'Living is knowing', maintained Maturana and Varela in 1980; this statement is based on Maturana–Varela–Bateson Theory. According to this theory, life and cognition follow the same kind of process and share, therefore, the same nature; a learning structure is a living structure and it is living whilst learning.

Learning in complex environments, according to Rullani (2002, p. 85–6), 'removes [...] free complexity from the environment and metabolizes it in the structures of the system as managed complexity'. Learning, in this sense, means managing complexity of the external environment. This is true for all complex systems. According to Holland (Waldrop, 1992), complex adaptive systems can evolve thanks to two kinds of learning. The first kind is 'learning by exploitation'; this involves improving and changing personal behavior. The second kind is more radical, and is 'learning by exploration'; this consists of trials to improve and change our mental models, and the way we think and look at the world. This second kind of learning is intrinsically more risky; you try, explore, and learn. Gharajedaghi (1999, p. 87) refers to these two kinds of learning as 'first-order' and 'second-order' learning. Bateson (1990) maintains that learning in complex systems is more effective if it comes from exploration, and introduces the idea of 'try and learn'.

It is well accepted that learning doesn't arise from calculations and plans (Piaget, 1967), but from action in rugged landscapes (Kauffman, 1995). Exploration, trial, action – these are the new key words it is necessary to learn.

GUIDELINES FOR STRATEGIC MANAGEMENT

Is the theory of complexity just an interesting scientific theory, or could it be something of great importance for our conceptions about organizations and strategy (Pascale, 1999)? Organizational theory has considered complexity as a structural variable of both organizations and their environments. In relation to organizations, Daft (1992) states that complexity is the number of activities or subsystems within an organization, observing that it can be measured according to three dimensions, namely vertical complexity, horizontal complexity, and spatial complexity. In relation to its environment, complexity has been seen as the number of different elements that an organization has to deal with at the same time (Scott, 1992).

However, the classic conception of business management considered firms as simple systems in simple environments. According to Olson and Eoyang (2001), this conception was greatly influenced by Newtonian science and the economic theories of Adam Smith. There has since been a shift of paradigm (Gharajedaghi, 1999) and the new paradigm considers firms as complex systems in complex environments.

Keene (2000) maintains that the principles of the theory of complexity must permeate the vision of organizations, as this will better equip them for instability and turbulence. Many different scholars consider organizations as CAS, and perceive that one, or more than one, of the principles of complex systems, apply to organizations. Therefore, the seven principles of complexity can be incorporated into management theory and practice, to allow organizations, viewed as complex adaptive systems, to evolve in complex environments. As previously stated, these principles can explain certain phenomena that happen within and between organizations, and in another way they can be considered as implications or guidelines for managers and entrepreneurs. In this second part of the chapter, we apply the identified seven principles of the theory of complexity to strategic management (see Table 13.2), while in the third part we will consider supply management in particular. Before this application, first we build a theoretical model considering the theory of complexity applied to firms. Each of the following paragraphs will consider one of the seven principles of strategic management of complexity.

Table 13.2 Principles of the theory and management of complexity

	Principles of theory of complexity	*Principles of management of complexity*
1	Auto-organization	Auto-organization
2	Edge of chaos	Creative disorganization
3	Hologrammatic principle	Management sharing
4	Impossibility to forecast	Strategic flexibility
5	Power of connections	Network organization
6	Circular causality	Management through virtuous circles
7	Try and learn	Learning organization

Auto-organization

To have bottom-up auto-organization, a balanced equilibrium between cooperation and competition is necessary. Eisenhardt and Galunic (2000) apply the biological idea of co-evolution to organizations; they should evolve together with other organizations and with the environment. Depending on the chosen level of detail, it is possible to apply the principle of auto-organization to the firm, considering it as a system, or to the system of firms when they form networks (including supply networks) or clusters. Applying auto-organization to a single firm involves seeking out distributed intelligence. According to the principle of auto-organization, few rules are sufficient to generate complex behavior through bottom-up emergence. Organizations, therefore, should encourage active participation of employees, as an instrument to 'complexify' them (Ashmos et al., 2002). Intellectual contribution by anyone in the organization is fundamental (Hamel, 1997) to reach distributed intelligence (DI), which is a function of the strategic relevance of human and social assets (McKelvey, 2001). It represents a kind of network within an organization, where knots are generated by intelligence of the individuals (H, human capital) and connections are generated by people conversing and interacting (S, social capital). These dynamics don't augur the end of leadership, but rather herald a new type of complex leadership (Wheatley, 1994; Keene, 2000; Marion and Uhl-Bien, 2001).

Looking beyond the firm boundary, competition is increasingly viewed as competition between coalitions or networks, not between single firms. It is necessary for organizations to embrace new forms of collaboration, not only to decrease competition against other organizations, share risks, and combine complementary resources, but also to develop new knowledge. A particular case of auto-organization is represented by Italian districts, which seem to be one of the richest elements of analysis for researchers in the field of theory of complexity (Quadrio Curzio and Fortis, 2002). Districts are open CAS, generated and continually renewed by processes of auto-organization (Corò and Rullani, 1998; Normann, 2001; Rullani, 2002).

Creative disorganization

The edge of chaos is reached by firms through creative disorganization, a principle similar to the concept of innovation proposed by Schumpeter (1942), who defined 'the agglomerates of explosion' generating change as 'perpetual storms of creative destruction'. In CAS, and therefore also in organizations, when a higher degree of autonomy is given to agents to make decisions locally, outcomes are then allowed to emerge in a deviation-amplifying way or through positive feedback (Dooley and Van de Ven, 1999). Many of the creative activities found in firms emerge in this fashion. Thus it is necessary to dispel the idea that success comes from stability and order: life and innovation are generated at the edge of chaos, between formal and informal structures (Pascale, 1990; Stacey, 1991, 1992). Dee Hock, one of the founder members of VISA, calls his organization a 'chaord organization', where chaord signifies an appropriate mix of chaos and order (Savage, 1996).

Creative disorganization can be facilitated along three related directions – organizational structures, directional styles, and management. Considering organizational structures, it is necessary to create flat structures (Peters, 1992; Savage, 1996), lateral roles of co-ordination (Foster and Kaplan, 2001), and decision decentralization (Pascale, 1990; Peters, 1992). Regarding directional styles and culture, it is necessary to develop intra-entrepreneuring (Peters, 1992; Keene, 2000), not to fear mistakes (Pascale, 1990; Peters, 1992; Foster and Kaplan, 2001), and not to fear conflicts, but exploit them (Pascale, 1990; Ciappei and Poggi, 1997; Olson and Eoyang, 2001). Looking at management, it is important to use techniques to develop single and group creativity (Peters, 1992; Foster and Kaplan, 2001). It is important to take into consideration that humans feel the necessity to create. The future belongs to those who can imagine it, because 'creating is living twice' (Camus).

Management sharing

The edge of chaos principle seeks discontinuity, but the hologrammatic principle asks for continuity. Complexity is a blend of continuity and discontinuity, and appropriate blends should be present in organizations to support their achievement of success. Continuity means continuous improvement and operational excellence; this could be reached by management sharing.

On a social level, management sharing requires sharing of values. Peters and Waterman (1982) describe excellent organizations as those that have 'strong cultures' and people are driven more by shared values than by rules, orders and formal procedures. 'Values are vectors: they express the force in a given direction' (Jaques, 1989, p. 112). A useful method to transmit the most important values in organizations is to rely upon symbols, myths, or stories (Olson and Eoyang, 2001).

At a strategic level, management sharing requires sharing of vision. Senge (1990) and Savage (1996) use the hologrammatic principle and fractal forms to describe vision; it is inside the firm, and the firm is inside it. To be transformed into something powerful, vision needs words, since it has to be exciting (Foster and Kaplan, 2001), actions, as it has to be real and tangible (Bennis, 1997), and relationships, since it has to be approved and shared by everyone in the organization, that emerges from some form of bottom-up process (Olson and Eoyang, 2001).

At an organizational level, management sharing requires team building and network relationships. It is necessary to share as uncertainty through isolated and unshared action is risky; referring to risk and uncertainty implicit in the innovation process, Hayes and Abernathy (1980) termed it the 'choice of the gambler'. Ohmae (1989) concluded that 'in a complex and uncertain world it is better not to play it alone'. The theory of complexity can teach us something about team building. Olson and Eoyang (2001) maintain that teams are auto-organized systems, within which diversity has to be embraced, since it is a source of innovation (Keene, 2000).

Strategic flexibility

Strategic flexibility, as a principle of the management of complexity, is related to the impossibility to forecast as a principle of complexity, and it is a known requirement for organizations. Aragòn-Correa and Sharma (2003) identified three kinds of uncertainty that organizations have to face: 'environmental', 'organizational', and 'decisional'. Change is open, unpredictable and created by us and the interconnections with other subjects: open and exploratory strategies are more useful than long-term forecasting to enable positive development in a complex and changing environment; 'late to market' implies philosophical, as well as commercial, failure.

The need for rapid response requires 'adaptability, readiness, and flexibility' (Rabey, 2001). Adaptability is reached through building 'what-if' scenarios. Forecasting then becomes the building of different options, or scenarios. Readiness is reached through external world monitoring and constant attention to weak signals, as competition becomes 'competing to imagine the future' (Hamel and Prahalad, 1994). Attention to weak signals is critical; organizations should behave like 'high reliability organizations', such as nuclear power stations, where weak signals are taken seriously and generate strong responses (Weick and Sutcliffe, 2001). According to Harris and Zeisler (2002), reaching the edge of chaos is the best way to seize weak signals. In our opinion, it is important to build an active monitoring system, create an internal and external network for knowledge accumulation, and establish a spontaneous empathy with people and markets. Strategic flexibility has to be pursued by organizations. Strategic flexibility means adaptability, readiness, and much more.

Network organization

The principle of the power of connections requires a network organization. The metaphor for old-fashioned organizations is the castle, but the metaphor for what's happening today is the network (Kelly, 1997). Firms have to create networks that involve suppliers, clients, firms, banks, research centres and universities, public bodies, trade associations and trade unions, and socio-cultural associations, i.e. supply networks and many other networks.

Starting from transaction cost theory, it is possible to consider networks as hybrid organizational forms that combine elements of market coordination (price mechanism) with hierarchy (planning mechanism). Networks of companies, therefore, represent intermediate solutions between vertically integrated firms and the 'market', i.e. the complex group of independent firms with whom exclusively short-term or 'spot' transactions are established.

Innovation occurs in complex networks; Rothwell and Zegveld (1985) describe innovation as 'a complex network of paths of communication, both inside and outside organizations, which link different internal functions and link the organization to the scientific and technological community and to the market'. Since the relationship with rapidly changing technologies requires continual updating, Granstand and Sjolander (1990) maintain that firms increasingly turn towards their external environment to satisfy their technological demand and maintain or reach technological pre-eminence. Firms therefore form networks for innovation (De Bresson and Amesse, 1991).

Experts of the theory of complexity maintain that network organization is the practical translation at an organizational level of what happens in nature (Kelly, 1997). Following nature there is therefore a shift from a firm-based view to an industrial view (hierarchy, market), to an eco-systemic view (network) and from 'working for someone' (hierarchy) to 'working with someone' (network) (Battram, 1999).

Management through virtuous circles

Virtuous circles have not been considered as important economic and managerial themes, even if they were implicit in some models. For example, Freeman (1982, p. 214) states 'In the model Schumpeter (Mark) II there is a strong loop characterized by positive feedback from successful innovation to improvement of activities of research and development, which gives origin to a virtuous circle ...'. Hegel used to describe philosophy as 'the circle of circles'. In our opinion, 'the circle of circles' regarding organizations is the one between innovation and development. Innovation generates development, which generates new innovation, and so on. Circles are often not so simple, since there are usually connections between them. Connected circles are defined in an effective way by Gharajedaghi (1999), who considers, for example, the circle 'innovation–development–knowledge–relationships'.

Learning organization

The importance of learning for complex systems was underlined explaining the 'try and learn' principle. Learning is fundamental for organizations too and many authors maintain that successful organizations are 'learning organizations'. Garvin (2000, p. 11) defines a learning organization as 'an organization skilled at creating, acquiring, interpreting, transferring, and retaining knowledge, and at purposefully modifying its behavior to reflect new knowledge and insights'. It is possible to talk about a learning organization if learning and innovation generate a virtuous circle (Ciappei and Poggi, 1997). Although global understanding about knowledge management is rapidly increasing, learning organizations have been embraced in theory but are still surprisingly rare in practice (Garvin, 2002). Numerous examples of practical learning organizations come from Japan, where there is an almost fanatic devotion to learning, both inside organizations and beyond (Imai et al., 1985; Senge, 1992; Nonaka and Takeuchi, 1995).

Argyris (1982), Morgan (1991), and Senge (1992) distinguish between 'single loop learning' and 'double loop learning' within organizations, while Garvin (2000) identifies three modes of learning – intelligence, experience, and experimentation. We prefer to talk about 'linear' (similar to learning by exploitation) and 'circular' (similar to learning by exploration) learning. The first kind of learning requires behavioral change, while the second requires cognitive change that leads to dispensing with old mental models, and has to be earnestly sought by organizations. Therefore it is necessary to create within firms a continuous learning culture, in particular one that tolerates mistakes (Gharajedaghi, 1999). Sometimes a failure can be productive, and a success unproductive (Nadler, 1989).

GUIDELINES FOR COMPLEX SUPPLY MANAGEMENT

Supply management refers to the process of how products are designed, sourced through often-complex networks, manufactured and distributed from raw material to the end customer (Smock, 2003). There are different levels of complexity relating to supply management (Romano, 2003). The actors of the supply network are, in general, autonomous or semi- autonomous; they carry out different activities and interact with each other. The supply networks involve continuous physical (materials/products), informational and financial flows; supply networks extend on one side to original source of raw materials and on the other side to the end consumers.

Increased globalization and accelerated product development are adding complexity to the supply chain, making its effective management more critical. 'Every manufacturer's supply chain is expanding and becoming increasingly complex', says Doug Engel, partner and one of Deloitte's national manufacturing industry leaders. 'However, complexity is not the enemy to the supply chain – effectively managing complexity can be a manufacturer's greatest asset', (Engel quoted in

Chemical Market Reporter, 2003). So therefore the greatest challenge facing supply chain leaders today is complexity. Deloitte Touche Tohmatsu studied nearly 400 US manufacturers in an attempt to understand the issue, and produced a study entitled 'The challenge of complexity in global manufacturing' (Burnson, 2003). Wilding (1998) maintains that there is deterministic chaos in supply chains and Choi et al. (2001) that a supply network is an emergent, complex, adaptive phenomenon and that a delicate balance between control and emergence has to be found. Since supply networks can be seen as CAS, it is possible to use the same instruments for their comprehension. Artificial 'agents' are generally used to model complex systems and are now frequently used to model supply chain phenomena. One of the key developments in research in the industrial network tradition has been the changing focus of study from the structural features of networks to a concern with their dynamics (Easton et al., 1997), mainly credited to the studies by the IMP group.

In this third part of the chapter, we apply the identified seven principles of theory of complexity and strategic management of complexity to supply management (see Table 13.3). Each of the following paragraphs will take into consideration one of the seven principles of supply management.

Distributed intelligence

> [T]he actions of each unit depend upon the states and actions of a limited number of other units, and the overall direction of the system is determined by competition and coordination among the units subject to structural constraints. The complexity of the system thus tends to arise more from the interactions among the units than from any complexity inherent in the individual units per se. (Tesfatsion, 1996, p. 1)

This situation parallels in a profound way the nature of industrial networks and the way network structure emerges and evolves (Easton et al., 1997).

Table 13.3 Principles of theory of complexity, management of complexity, and complex supply management

	Principles of theory of complexity	*Principles of management of complexity*	*Principles of complex supply management*
1	Auto-organization	Auto-organization	Distributed intelligence
2	Edge of chaos	Creative disorganization	Creative new product development
3	Hologrammatic principle	Management sharing	Partnership
4	Impossibility to forecast	Strategic flexibility	International manufacturing/ sourcing
5	Power of connections	Network organization	Supply network
6	Circular causality	Management through virtuous circles	Integration and continuous improvement
7	Try and learn	Learning organization	Learning supply network

Relationships of contemporary collaboration and competition are important even in partnership relationships; lean supply emerges as a kind of business characterized by competition and dynamic collaboration among actors (Lamming, 1993). These relationships are reached through interdependence of knots, that is distributed intelligence; if one would like to see a more creative and adaptive response from the supply network, then one must give more autonomy to the firms in the supply network, essentially increasing dimensionality – the degrees of freedom available for potential response.

The degree of innovation by suppliers is directly proportional to the amount of autonomy that suppliers receive when working with customers (Choi et al., 2001). A small circle of close friends has to be built, where suppliers can even become technological leaders, innovators, and leading partners (Lamming, 1993).

Supply networks display non-linear behavior that centralized planning can't regiment. There is necessity for a bottom-up approach. Similarly, in adaptive supply networks, intelligence and control aren't hoarded in one single 'hub' (for example, an original equipment manufacturer), but rather delegated to 'spokes' (suppliers) that use their freedom of action to fix local issues (Radjou et al., 2002). Companies need to build the supply chain from the bottom up, not the top down as they have done in the past (Sherman, 2001).

Creative new product development

Complexity is defined as '.. orderly enough to ensure stability, yet full of flexibility and surprise' (Kauffman, 1995, p. 87). This is precisely the kind of behavior that is so characteristic of industrial networks in the mixture of stability and change (Håkansson, 1992). This is particularly true for the new product development process, where relationships between different actors are so important. The capabilities which serve the innovative process are located within the supplier, and within the purchaser, and emerge as a consequence of the interactions between the two parties. Stability is granted by a shared procedure (i.e. stage–gate methodology), something that lets the actors speak the same language.

Sometimes it could be useful to adopt creative techniques for collaborative new product development. In particular we suggest a methodology that we developed in the European project CREATE (www.diegm.uniud.it/create/), articulated into five steps to generate collaboration and new ideas: external and internal mapping, predisposition, creative process, and evaluation.

Regarding 'external mapping', enterprises select external stimuli, interpreting them according to their knowledge. In order to collect external signals, it is essential for organizations to take part in exhibitions and meetings, get in touch with suppliers and develop interesting ideas about the relationship between them and the enterprise itself. 'Internal mapping' is concerned with valuing the inner cognitive capital in order to exploit its potential and aid new business ideas to rise up. A technique that can be used for internal mapping is a creative targets list, proposed by E. De Bono (1992). This technique may be used both to search not yet evident internal problems and to point out some new focus. 'Predisposition' is concerned with creating an internal environment that may favor new ideas and rapidly eliminate old-fashioned ones. We think that preventive creative training can be very useful to make people comfortable with such an argument, and in particular with some basic techniques and procedures. 'Creative process' is the generation of ideas. In this phase it can be very useful to involve suppliers in order to realize a sort of 'cross-fertilization' (Koestler, 1975) and produce new ideas to improve the purchasing process. A possible technique to be used is context modifying, suggested by Foster and Kaplan (2001). There are different ways to modify a meeting context; the first is to modify the social environment where the meeting takes place, second is to modify the physical context, and third is to change the mental approach to problems by using reversed thinking. 'Evaluation' consists of the selection of the best ideas according to the inner judgement criteria of the enterprise. The technique we suggest for this phase is six thinking hats, invented by De Bono (1992). It allows users to separate logic from emotions, creativity from information, and idea generation from idea evaluation, and to consider ideas from different points of view.

Partnership

Sharing is reached through partnership and integration. Partnership is a 'strong inter-company dependency relationship with long term planning horizons' (Stuart, 1993). The critical role of trust in the process has to be underlined (Lamming, 1993); mutuality, shared objectives and interests are of considerable interest. The 'area of contact' between suppliers and customers is amplified, from firms' independence to continuous integration in operational processes, new product development, and strategic planning.

Integration occurs on three levels (Zanger, 1998). On an organizational level the problems of the individual partners are fixed on a contractual basis with a view to mutual fulfilment of objectives. Material integration results from specialization along the value chain or from reciprocal resource utilization in the production process. Informal integration comprises know-how interchange and permeates the other two levels. Actors in the supply network have to be integrated with and able to accommodate decisions made elsewhere, otherwise they won't be part of the supply network of the future (Sherman, 2001). Integrated supply networks must become a way of life; changing is fundamental to meet complex demands.

International manufacturing/sourcing

Constantly adapting to changing circumstances is now the norm (Radjou et al., 2002). Firms that adjust goals and infrastructure quickly, according to changes in their customers, suppliers, and/or competitors, will survive longer in their supply

networks than firms that adhere to predetermined, static goals and infrastructure and are slow to change (Choi et al., 2001). Efficient supply chain management is still essential for functional products, but a flexible supply chain is fundamental for innovative products (Fisher, 1997).

Flexibility can be reached through the right geographical choice of suppliers. Supply networks are moving towards a global supplying system (Lamming, 1993). Varaldo (1997) maintains that originally globalization centred on commerce, but now it is on production. According to a survey by Osservatorio TeDIS in 2002, 90 per cent of the interviewed Italian small or medium enterprises outsourced at least part of their activities and 56 per cent of these firms turn into strategic suppliers, i.e. suppliers linked to the customer through partnership relationships. With particular reference to North-Eastern Italy, a survey by Fondazione Nordest (Marini et al., 2003) reported that 95 per cent of interviewed entrepreneurs expected positive futures for firms choosing to internationalize, and 83 per cent that it is essential to internationalize to gain competitive advantage. International trade is not a zero-sum game. Its benefits will be widespread over time.

Supply network

Network organizations are created through supply networks. The creation and evolution of the structure of industrial networks is seen to emerge through the on-going micro processes of action and interaction among and within firms. A model of the interaction between dyadic relations in industrial networks was developed by Easton et al. (1997).

Therefore, it is necessary to migrate inflexible supply chains to adaptive supply networks; brittle supply chains risk snapping under the disruptive force of business drivers (Radjou et al., 2002). Individual capacities in the supply network have to be valued (Clark, 1989); suppliers should be involved even in the design phase. Dynamic networks of suppliers, characterized by flexibility and experimentation capacity, are necessary.

The management of supplier relationships is a central, yet complex, element of purchasing's strategic role. A complex adaptive supply network should be generated, i.e. a collection of firms that seek to maximize their individual profit and livelihood by exchanging information, products, and services with one another (Choi et al., 2001). Therefore we need a more holistic view towards supply networks. For example, supply strategy as the extension of operations strategy to inter-organizational supply networks. Supply strategy is 'an holistic approach to formulate and implement rational strategies to create, stimulate and satisfy end client demand through innovation of products, services, structures and infrastructures of the supply network, in a global and dynamic environment' (Harland et al., 1999). There is evidence from studies in strategic management that organizations including Benetton, Rank Xerox, Toyota, Nissan, and Caterpillar have taken a more strategic, holistic approach to manage the entire network of supply (Jarillo, 1993). There is a need for knowledge networking too, seen as the process of combining and recombining one another's knowledge, experiences, talents, skills, capabilities, and aspirations in ever-changing, profitable patterns (Savage, 1996), to develop the potential for synergy.

Innovation generation has increasingly been recognized as an outcome of interaction between a firm and various outside entities. According to this view, supplier involvement and alliances are routes to innovation generation. Despite this realization, only very limited conceptual research has focussed on innovation generation in buyer–seller relationships in supply chains. To alleviate this important gap in the literature, a conceptual model of innovation generation in buyer–seller relationships in supply chains was developed by Wilkinson et al. (2004). They maintained that innovation generation in supply chain relationships is caused by interactions between buyers and sellers. Due to knowledge redundancy effects, new relationships are likely to help generate radical innovations, while old relationships are essential to innovate incrementally and make innovations commercially viable on a continuous basis. This highlights, once again, the coexistence between order and disorder, continuity and discontinuity, continuous improvement and radical innovation.

Integration and continuous improvement

Virtuous circles are important features to be found even within operational supply management. Graves (1987) underlines the difference between American and Japanese research and development regarding circularity: 'The American system of research and development is unidirectional, while Japanese processes, with their internal feedback mechanisms, are circular and dynamic. [In the Japanese system] relationships are more organic and persons in charge and managers maintain an informative flow through the whole system'. Thus it is necessary to develop a new model that utilizes innovation from suppliers' environments and allows growth (Lamming, 1993). Commitment, trust and continuous improvement are tightly linked (Lamming, 1993). An important virtuous circle for supply management is the one between partnership and continuous improvement; partnership causes continuous improvement, which generates partnership, and so on.

Learning supply network

A supply network is not effective if it is not a learning supply network. Joint ventures, alliances, and networks are first and foremost exercises for learning (Lamming, 1993). Dodgson (1991) and Doz and Shuen (1988) underline that in continuous collaborations there are three kinds of learning – learning about partners, learning about tasks to be carried out, and learning about results. Japanese networks can generally be considered as learning supply networks (Imai et al., 1985, p. 372); 'whoever participates in the development process is involved in learning, even suppliers. [...] It is this kind of "enlarged learning" that supports the dynamic process of product development among Japanese firms ...'.

Research studies on learning within supply management are not common. To date a notable exception within the supply chain field is Richard Hall (1997) who has used the social learning cycle, developed by Boisot, to explore the knowledge acquisition and diffusion processes required to create new capabilities within a supply context. It is hoped that an understanding of the organizational learning processes required to facilitate the creation of inter-organizational capabilities can be expanded to supply management (Batchelor, 1998). Some attention has been given to the application of knowledge management to supply management, as witnessed by the concept of knowledge supply networks. Being an extension of the conception of supply chain management familiar to operations managers, knowledge supply networks provide a natural framework for operations management to contribute to the issues of knowledge management and intellectual capital, while retaining the tradition of practicality (Mak and Ramaprasad, 2003).

CONCLUSION

In this chapter, we provided initially a theoretical framework to understand the principles that allow CAS to evolve in rugged landscapes; in this part we identified seven principles of the theory of complexity. Since many scholars consider firms as CAS, we have in the second part developed the seven principles of theory of complexity into seven principles of management of complexity. Firms, like living systems, evolve in rugged landscapes. In the last part we focused our attention on supply management, identifying in particular seven principles for complex supply management. In conditions of high complexity, the supply network has to adapt and create new opportunities, finding a dynamic equilibrium between control and emergence.

Complexity is a source of opportunities and threats. By knowing the principles used by living systems to maximize their adaptation, organizations may seize opportunities and reduce threats. However, the list of principles for complex supply management let managers and entrepreneurs think that they should all be adopted simultaneously and therefore that they comprise an integrated and coherent set of criteria for supply system design. However, it has to be underlined that some of them may be conflicting or may be too expensive if compared to the potential benefits they may provide. Therefore, these principles should be considered as general guidelines that have to be adapted and customized for every organization. The explained principles, in the end, contribute to create a different concept of management and strategy, one in which the organization participates and responds to the system in which it operates, rather than tries to control and direct it. Firms jointly create both their own destiny and the destiny of others. In this regard firms act so as to preserve and create the ability to act through the futures they shape for other firms on whom they depend as well as themselves.

Managers and entrepreneurs are acting as leaders because relationship and network outcomes are co-produced by the actors involved, but no one manager controls the network. In short, managers are participants in complex adaptive systems in which order emerges in a bottom up, self-organizing way (Easton et al., 1997; Wilkinson and Young, 2003). This can be considered to be a change of paradigm and it should be taken into consideration by supply management practitioners. In the mainstream business literature we are beginning to see the emergence of this type of management thinking as firms come to see themselves as parts of business ecosystems in which cooperative and competitive processes act in a complementary way to shape the dynamics and evolution of the ecosystem (Moore, 1995; Moore, 1996; Easton et al., 1997).

Researchers could therefore follow two directions. Following theoretical developments, they could provide new insights and new concepts for supply management. In another way, they could use the operational instruments developed by scientists studying the theory of complexity, such as system dynamics tools or agent based simulations, to develop models of complex phenomena in order to understand better the dynamics involved in supply networks. Greater knowledge relating to both directions is required to further the understanding of supply management in complex adaptive systems.

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