Available online at www.elixirpublishers.com (Elixir International Journal)

Production Management

Elixir Prod. Mgmt. 42 (2012) 6106-6110

ISSN: 2229-712X

The holonic approach for flexible production: a theoretical framework

Gandolfo Dominici

Faculty of Economics, University of Palermo – Italy, Viale delle Scienze ed. 13 – 90128 – Palermo – Italy.

ARTICLE INFO

Article history:

Received: 2 November 2011;
Received in revised form:
15 December 2011;
Accepted: 26 December 2011;

Keywords

Holonic production systems,
Production agility,
Complex systems,
Systemic approach.

ABSTRACT

This paper discusses the body of knowledge about Holonic Approach to theoretically demonstrate how Holonic Production System (HPS) can be a convincing choice to overcome the problems of traditional production systems' architectures. Today, enterprises are trying to find ways to manage the growing environmental complexity that is well described by Complex Systems Theory (CST). After the focus on the main problem regarding environmental complexity, the Holonic system and the Holonic Production System will be analyzed. The paper will focus the potential of HPS to adapt and react to changes in the business environment whilst being able to maintain systemic synergies and coordination through the holonic structure where functional production units are simultaneously autonomous and cooperative.

Introduction

The main challenge that today production systems have to face is environmental complexity.

A definition of complexity is given by Sherman & Shultz (1998. p. 63) from the Santa Fe Institute:

«Complexity refers to the condition of the universe which is integrated and yet too rich and varied for us to understand in simple common mechanistic or linear ways. We can understand many parts of the universe in these ways, but the larger and more intricately related phenomena can only be understood by principles and patterns – not in detail. Complexity deals with the nature of emergence, innovation, learning and adaptation».

While mass production showed its effectiveness in stable environments and with continuous growth trends as it happened to be in the 1980's; since the beginning of the 90's, this production system has begun to prove its weaknesses due to the growing instability of business environment and of systemic complexity. This happened because the hierarchical pattern on which mass production was founded presumed the steadiness of social, economic and technological factors (Dominici, 2008). In mature markets it is necessary to supply a broad variety of products in order to adhere to the need of customers whose role has changed from "consumer" to "prosumer". It was predicted already in 1972 by McLuhan & Nevitt (1972) in "Take Today" that electronic technologies would transform consumers into producers. Some years later, in 1980, the futurologist Alvin Toffler (1980) in "The Third Wave" coined the term "prosumer", predicting the blurring of the distinction between producer and consumer due to the saturation of markets with standardized products which would have pushed towards the search for higher levels of differentiation and personalization of products.

The spread of Internet accelerated this paradigm shift which brought profound changes in the society and consequently in the market; this happened because the Internet made it possible for firms the use of a low cost, worldwide extended, informative infrastructure.

These changes caused the shift from "mass production" to "mass-customization", creating new needs for agility of firms' structures that now need to develop extremely flexible production structures in order to:

a) duly react to the market environment's turbulences;
b) survive production system changes through the adoption of new technologies;
c) adapt to the uncertainties of production systems in such environments.

To obtain this kind of flexibility and to manage complexity it is important to rethink the architecture of the firm. Neither hierarchical or heterarchical systems are able alone to realize these requirements (Dilts et al., 1991; Crowe & Stahlman, 1995).

Hierarchical systems are characterized by a rigid structure which makes it very hard for them to react to turbulences in an agile way. On the other hand heterarchical systems are networks of elements with common aims in which each element shares with the others the same "horizontal" position of power and authority. Though heterarchical systems can easily adapt to environmental changes and turbulences, their control system cannot guarantee the high level of performance needed for the decision processes of the industrial firms.

Theoretical Framework

The main challenge for production systems is represented by the growth of environmental complexity. Complexity is a multi-dimensional and multi-disciplinary concept. Smarr (1985) in a famous article on the journal "Science" claimed that it is not possible to define and to measure complexity. In spite of the fact that probably, as Smarr says, it is difficult to draw a precise and exhaustive definition of complexity, we can consider a complex system as a system with a high number of parts and of systemic states. To understand the concept of complexity, we have to consider two opposite notions: diversity and unity. Firms are complex systems formed by a set of subsystems and interacting with supra-systems that are connected one to each other by feedback loops leading to the creation a complex system.

Tele:
E-mail addresses: gandolfo.dominici@libero.it

The growth of complexity can be analyzed with the theoretical framework given by Complex Systems Theory and specifically of a Complex Adaptive System (CAS). A CAS is a system formed by a set of participants interacting with each other and co-evolving, continuously redefining their future situation.

In particular some of the properties of CAS are of great utility for our analysis (Levanti, 2010; McCharty et al., 2000). These properties are:

- *Emergence*. This property relates to the appearance of a new systemic behavior, as systemic response to environmental factors, because of the collective behavior and not of the individual behavior of each part. Some of the path and properties of networked systems come from spontaneous interactions among participating firms; they are not caused by behaviors intentionally controlled or coordinated by the management.
- *Self-Organization*. This property refers to the unplanned creation of augmented order, emerging from the internal dynamics of the system as learning, process variation, tuning and improvement. The interactions among process variations of the single parts, individual learning and tuning according to the reciprocal exchange of information and the consequential local improvements and adjustments affect the performance of the whole system. The systemic-firm creates endogenous process dynamics that spontaneously bring to enhance its organization (Kauffman, 1993). It constantly models itself, modifying its borders, creating and recreating its stock of knowledge and capabilities harmonizing with the external environment.
- *Path dependence*. The overall behavior of the systemic-firm depends on the weaving among current flows/stimuli received and the structural elements coming from the past stimuli and behaviors (Bertelè, 1994). This implies that historical contingencies have a role, influencing the structure and the behaviors of the firm (Arthur, 1989).
- *Operational closure and thermodynamic openness*. The system is autonomous. Its invariant organization makes it possible to identify the system itself, regardless of its specific structure in each space-time momentum (Bertschinger et al., 2006). The system exchanges energy with the external environment in terms of resources, knowledge and capabilities. From this channel the system receives the stimuli which (after a process of selection) can activate internal structural changes in order to preserve the organization closure and to guarantee the survival of the system.
- *Co-evolution*. The firm, in order to operate its strategies, has to continuously adapt to the other firms in the system and to environmental stimuli (Anderson, 1999; Lewin & Volberda, 1999; Volberda & Lewin, 2003). An analogy by Fontana & Ballati, (1999, p.15) explains this concept: *«From an evolutionary point of view, an adaptive organization is like a ship on the open sea that has to rebuild itself staying afloat»*.

The new scenario is characterized by the essential role of the customer, thrived to the point that the supply chain has begun to be defined as the “demand chain” (Balckwell & Blackwell, 1999) Literature on this topic shows several trends which manufacturing and supply chain systems have to settle with (Frederix, 2004; Gou et al. , 1998):

a) the paradigm shift from mass production to semi-personalized production;

b) the opening to collaboration with other agents and firms in order to speed up production innovation and processes;

c) the critical role of effective and efficient cooperation inside the inter-firm network;

d) the understanding of the problems concerning the implementation of a centralized control system between different entities with different information, experiences, activities, objectives and decisional authorities.

These changes call for new organization structures with characteristics of agility and dynamic adaptivity.

Traditional hierarchical systems show a number of insufficiencies to work in highly complex environments:

a) they strongly limit the reconfiguration capacity, the reliability and the growth capacity of the organization;

b) their complexity grows together with the size of the organization (Hatvany, 1985);

c) communication among the elements of the system is strictly determined ex ante and vertically limited (Bruseel et al. 1999);

d) the structure’s modules may not take initiatives, therefore reducing the system’s readiness to react thus resulting not agile in turbulent environments environment (Valckenaers et al., 1994);

e) the structure is expensive to make and to preserve.

Heterarchical systems do not have the limits of hierarchical systems (but as we will see they have other kinds of limits), as they are capable to obtain flexibility and adaptability to exterior stimuli. In these systems every hierarchy is banned and power is given to the single “agents” of the system. Agents relate with their environment and with other agents according to their own characteristics and finalities. Control is based on negotiation due the lack of hierarchy.

To understand this kind of structure it is important to specify what an agent is. In the field of artificial intelligence, the term agent is used to define the intelligent elements of a system who observe and act in the environment as entities capable of awareness and purposive behaviors; such agents must have the following attributes (Moyaux et al. , 2006; Paolucci & Sacile, 2005):

- *autonomy* - they act without the help or guide of any superior entity;
- *social ability*-they interact with other agents;
- *reactivity*-they perceive their environment and respond rapidly to changes;
- *pro-activity*-they are able to have initiative and specific behaviors for a specific scope.

In a heterarchical manufacturing system, the relation between the work station and supply orders is such that every supplier has direct contact with the work station in order to take advantage of all possible options to face unexpected fluctuations in supply and/or demand.

In spite of these qualities also heterarchical systems have strong restrictions to achieve the goal of performance and agility. In spite of their agility, heterarchical systems are not able to operate following predefined plans, hence their behavior is hardly predictable, increasing variability in systemic dynamics so that it become even harder for managers to manage firms’ processes. Heterarchical structures work well only in simple, non complex and homogeneous environments with abundance of resources (Valckenaers et al., 1994), while in complex environments they can bring to instability because of their unpredictability; moreover, with scarcity of resources, they are not able to act efficiently due to the lack of planning. In other words managers need models to try to manage the complexity and take decisions, to do so they need what Jefrrey Kluger

(2008), referring to all living beings, calls with the neologism "Simplexity", a simplification of complexity, that with all its limits is something that our brain can manage.

In this sense an attempt was made by Anthony Stafford Beer, who, in 1972, introduced the concept of the firm as a *viable* system in his book: "*Brain of the firm*". Stafford Beer was the first to apply cybernetics to management, defining cybernetics as the science of effective organization.

According to Stafford Beer, a system is "viable" if it is "*able to maintain a separate existence*" (Beer, 1979). Hence, *"a viable system is a system that survives, remains united and is complete; it is homeostatically balanced both internally and externally and furthermore has mechanisms allowing it to grow and learn, develop and adapt, and thus become increasingly more effective in its environment."* (Stafford Beer, 1985).

Although Stafford Beer's Viable System Model (VSM) had the merit to introduce a systemic view in business studies, it had the limitation to consider the structure from a quite static perspective. A good attempt to overcome this limitation was that of Gaetano Golinelli and the Italian school of systemic science of the University of Rome La Sapienza that with the Viable Systemic Approach (VSA) tried to overcome the limit of the lack of dynamicity. The VSA widens VSM perspective considering all the possible relations between the firm and the external environment in a dynamic viewpoint. In fact, while Stafford Beer limited his analysis to the relations among the components of the enterprise-system, Golinelli considers also the relations existing among these components and the supra-systems in which the firm carries out its activities. According to VSA, the homeostasis of a system is determined by both the external normative regulatory environment (such as statutory legal requirements) that every system has to respect, and the internal self-regulatory environment (such as a business code of behavior) (Barile & Polese, 2010).

According to VSA, a viable system emerges by the activation of relationships which enable dynamic interactions among external supra-systems and internal sub-systems (Golinelli, 2010). This implies a paradigm shift from Stafford Beer's "static" view of system's structure to the view of a "dynamic" system, shifting the focus of analysis, from the individual components of the system and of the relations, towards a holistic view of the dynamics of interaction of the observed reality (Barile & Polese, 2010). In this perspective, the principle of "equifinality" refers to the attitude of different systems to reach the same end state starting from different structures and taking different evolutionary paths.

The Viable System theories are surely a step forward for the modeling of complex organizations, but a better conceptualization is necessary to achieve the levels of adaptability required by production systems. This models while can represent a valid framework for managerial decision making do not propose a production system able to assure both performance and reactivity at the same time.

The Holonic Paradigm for the Production System

In the field of systemic studies the holonic paradigm is probably the one that theoretically can give the best answers to production problems.

The holonic paradigm stems from the thoughts of Arthur Koestler (1967) who underlined how complex systems can originate only if they are composed by stable and autonomous sub-systems, which are able to survive turbulences and, at the same time, can cooperate forming a more complex system. Koestler highlights that analyzing both the biological and the physical universe emerges that, it is necessary to take into account the relations between the whole and the part of the entities observed. To understand the complexity of the world, according to Koestler, is not enough to study individuals or systems as independent entities, but it is crucial to consider such unities as simultaneously part of a larger whole; in other words, we have to consider it as a holon. The difference between an holonic system and a traditional holistic perspective is that holonic system considers both the parts and the whole at the same time with their hierarchies and functions.

Etymologically the term holon is a combination of the ancient Greek "ὅλος" with the meaning of "whole" and the suffix "ὄν" meaning "entity" or part; thus the whole is made of parts which unlike atoms are also entities. The holon is, indeed, a whole which includes, simultaneously, the elements or the sub-parts which form it and give it structural and functional meaning. Holons act as intelligent, autonomous and cooperative entities working together inside transitory hierarchies called "*holarchies*". A holarchy is a hierarchy of self-regulating holons working, in coordination with their environment, as autonomous wholes which are hierarchically superior to their own parts and, at the same time, are parts dependent by the control of superior levels.

Holons of the same level process elements and information coming from lower level holons and they transfer the results to higher level ones for further processing. Processes of holons belonging to level 'n' hence originate from process of 'n-1' level subordinated holons and at the same time are the input for the processes of 'n+1' superior holons.(Mesarovic et al., 1970; Mella, 2005).

The idea of holarchy is the strong point of the holonic approach. The holarchy allows the development and the implementation of very complex systems which are capable to efficiently employ resources, are resilient to turbulence and, at the same time, flexible to changes of the environment.

The multilevel logic of holarchy is similar to that Complex Adaptive Systems (CAS) which are basically multilevel (McKelvey, 1997, Dominici & Levanti 2011). In other words the interactions among different parts take place at different levels of analysis. This implies that there are other levels than the whole and the part. It is possible, indeed, to find sub-systems of several intermediate levels between the whole and the part. The number of these sub-systems depends on the finality and the subject of the analysis. In the field of research on managerial organization matrix, Baum & Singh (1994) focus their analysis on four levels (intra-organization, organization, population, community); also Kontopoulos (1993) finds four levels (local, semi-local, semi-global, global); while Monge & Contractor (2003) underscore five levels (single actor, dyad, triad, sub-group, global). These differences are due to the fact that the complex system cannot be defined in a natural-objective way, because there are not hierarchical natural-objective relations among systems, sub-systems and supra-systems. Every system can be a sub-system and a supra-system at the same time, like in the holonic system perspective.

Complex systems have "tangled composite" structures, inside which it is possible to outline several levels of analysis. At these levels, a number of semi-autonomous processes take place in order to improve the pay-offs of the participants. At the same time, these levels co-evolve interacting with other levels of the system. As Anderson (1999, p.223) points out: *«Agents (and* *clusters of agents that form stable subsystems) coevolve with one another, because changes in the distribution of behaviors among agents change individual fitness functions, and such shifts in turn alter behaviors».*

According to the CAS approach, the architecture of the organization is formed by the set of interrelated systemic relations. In this context, relations have different degrees of force, and dyadic or multiple connotations. In the network's architecture it is possible to spot different interconnected areas of strong interaction (cluster of firms) among firm-agents. These clusters of firms show emerging properties, self-organizing capabilities, a certain degree of autonomy; it can be considered a meso-system (Levanti, 2010). On the other hand, systemic firms and firms' clusters are connected by a set of weak links (both direct and indirect); this is the macro-system level.

Hence, in the holarchy we can highlight three levels. These levels are distinct but complementary and coexisting; they are:

- *micro-systemic*: regards the single firms;
- *meso-systemic*: considers the different sets of firms connected among them with strong links (firms' clusters);
- *macro-systemic*: involves the whole network system. www.ccsenet.org/ibr

Each of these levels acts a different role in the holarchy, interacts with other levels and coevolves with them.

What makes the holonic system particularly efficient in complex environments is that, within a holarchy, holons are able to dynamically create and change hierarchies and also to take part to different hierarchies simultaneously. The holonic system can therefore be defined as a global and organized entity made of interrelations among highly self-regulating operative units which are able to cooperate with each other, keeping their autonomy, seeking joint results and common aims. The three pillars of holonic systems are (Saccani, 1996):

The shared-value system in the organization consents the spontaneous and continuous interaction among groups of people who are far from each other and are not connected by legal or ownership ties, in order to take advantage of the economies of cooperation and of the augmented stability of the system. Examples of shared value systems are some of the elements of lean production, that are often embedded in the company's vision, such as the principle of continuous improvement (kaizen).

The distributed network information system which is the neural sub-system (Arbib, 1995) supporting real time supply of information between operating units which allows the quest of maximum income by better exploiting the imminent business opportunities.

The autonomous distributed hierarchy which is based on the capability of each autonomous part to become leader consistent with requirements of specific situations, caused by the turbulent modifications of the environment.

Every entity is able to directly interact with other entities without mediation. Due to this property in a holonic system each holon has potentially the same significance and the same responsibility; the involvement of a holon asoperative unit is based on its knowledge and competencies and is not a consequence of predefined leadership.

The Holonic Production System (HPS) is a production system adopting the architecture of the holarchy. This allows the production system to adapt and react to changes in the business environment whilst being able to maintain systemic synergies and coordination.

The HPS is made of holons seen as functional production units which are simultaneously autonomous and cooperative. These holons can be represented as networked agents who define different levels of a system (Ulieru & Cobzaru, 2005).

Every element is a holon (work cell, plant, firm, supply chain) with a holarchy of different levels (supply chain level, firm level, plant level, work cell level). At the supply chain level the interaction among firms, their suppliers and their clients takes place. It is possible to determine a subsystem for each firm at the supply chain level; this subsystem is an enterprise level holon. In the firm there is cooperation among plants and sales departments. Inside each plant there are several working cells which interact with each other; the working cell is the basic level of the holarchy described, which is self-controlled by the interaction among men and machines (Dominici, 2010).

Conclusions and further research

Although, as it has been pointed out, the HPS could theoretically represent a valid answer to pursue the necessary levels of agility of production systems, it has been narrowly implemented in practice and even less studied from a business studies perspective. Little research on this topic has been done outside the field of business engineering and computer science and very few studies of implementation of holonic-like systems can be found in the literature. Shen (2002) noted that IBM has been one of the first firms to adopt a system based on intelligent agents to avoid bottlenecks and smooth production. Jennings & Bussman (2003) developed a way to implement a standard modules system, where each module is flanked by an intelligent agent in order to create a holon which becomes the building block of the system; this system has been tested by Daimler-Chrysler in order to evaluate its resilience of the system. The result obtained was of 99,7% of the theoretical optimum and the system has been adopted in the factory of Stuttgart-Untertürkheim in Germany.

The HPS is surely not easy to implement, nevertheless a step-by-step approach for the introduction of this system in industrial production could be a valid choice to achieve the flexibility of production while giving a model for managerial decisions.

References

Anderson P., (1999), "Complexity Theory and Organization Science", *Organization Science*, 10 (3): 216-232.

Arbib M. A., (1995) "*The handbook of brain theory and neural networks*," MIT Press, Boston.

Arthur W. B., (1989), "Competing Technologies, Increasing Returns, and Lock-in by Historical Events", *Economic Journal*, 99: 116-131.

Barile S., Polese F. (2010), "Smart Service Systems and Viable Service Systems: Applying Systems Theory to Service Science", *Service Science*: 2 (1/2): 21-40.

Baum J.A.C., Singh J. V., (1994), "Organizational Hierarchies and Evolutionary Processes: Some Reflections on a Theory of Organizational Evolution", in Baum J.A.C., Singh J. V. (eds.), "*Evolutionary Dynamics of Organizations*", Oxford University Press, NY, pp.3-20.

Bertelè U., (1994), "*Sistemi di imprese e differenziali produttivi*", in Dioguardi G. (ed.), "*Sistemi di imprese. Le nuove configurazioni dell'impresa e dei mercati*" Etas, Milan.

Bertschinger N., Olbrich E., Ay N., Jost J., (2006), "*Information and Closure in Systems Theory*", in "*Explorations in the Complexity of Possible Life*", Artmann S. Dittrich P. (eds.), IOS Press, Amsterdam.

Blackwell R., Blackwell K. D., (1999) “The century of the consumer: Converting supply chains into demand chains,” *Supply Chain Management Review*, 3 (3) 22-32.

Brussel H. V., Bongaerts L., Wyns J., Valckenaers P., Ginderachter T. V., (1999) “A conceptual framework for Holonic manufacturing: Identification of manufacturing holons,” *Journal of Manufacturing Systems*, 18 (1): 35-52.

Crowe T. J. , Stahlman E. J., (1995), “A proposed structure for distributed shopfloor control,” Integrated Manufacturing Systems 6 (6):31-36.

Dilts D. M., Boyd N. P., Whorms H. H., (1991) “The evolution of control architectures for automated manufacturing systems," Journal of Manufacturing Systems 10(1): 79-93.

Dominici G. (2008), “Holonic Production System to obtain flexibility for Customer Satisfaction”, *Journal of Service Science and Management* 1 (3): 251-254.

Dominici G., Levanti G., (2011), "The Complex System Theory for the Analysis of Inter-Firm Networks. A Literature Overview and Theoretic Framework", *International Business Research*, 4 (2): 31-37.

Dominici G., (2010), “From Business System to Supply Chain and Production in Japan”. VDM Verlag, Germany.

Fontana W., Ballati S., (1999), “Complexity”, *Complexity*, 4 (3): 14-16.

Frederix F., (2004), “From production to a product perspective, New Industrial Scenario”, in Yoon S. et al. (eds.) *Evolution of Supply Chain Management, Symbiosis of Adaptive Value Networks and ICT,* Kluwer Academic Publishers, Norwell.

Golinelli G. M., (2010), “*Viable Systems Approach (VSA). Governing business dynamics*”, CEDAM, Milan.

Gou L., Luh P. B., Kyoya Y.,(1998) “Holonic manufacturing scheduling: Architecture, cooperation mechanism, and implementation,” *Computers in Industry*, 37 (3): 213-231.

Hatvany J., (1985) “Intelligence and cooperation in heterarchic manufacturing systems,” *Robotics & Computer-Integrated Manufacturing*, 2 (2): 101-104.

Jennings N. R., Bussmann S., “Agent-based control systems. Why are they suited to engineering complex systems?”. *IEEE Control Systems Magazine*, 23(3): 61-73, 2003.

Kauffman S. A., (1993) “*The Origins of Order: Self-organization and Selection in Evolution*”, Oxford University Press, NY.

Kluger J., (2008), “*Simplexity*”, John Murray Publishers.

Koestler A., (1967) “*The ghost in the machine*” Arkana.

Kontopoulos K. M. (1993). “The logics of Social Structure”,. Cambridge University Press, New York (NY).

Levanti G., (2010) “*Il governo dei sistemi reticolari di imprese*”, FrancoAngeli, Milan.

Lewin A. Y., (1999), “Application of Complexity Theory to Organization Science”, *Organization Science* 10 (3): 215-223.

McCarthy I. P., Rakotobe-Joel T., Frizelle G., (2000) “Complex systems theory: implications and promises for manufacturing organizations”, *International Journal of Manufacturing Technology and Management*, 2, (1-7): 559-579.

McKelvey B., (1997), “Quasi-natural Organization Science”, *Organization Science*, 8 (4): 352-380.

McLuhan M, B. Nevitt, (1972), “Take today: The executive as dropout.” B. J. Harcourt, Boston (MA).

Mella P., (2005) “*La Rivoluzione Olonica: Oloni, olarchie e reti oloniche, Il fantasma del kosmos produttivo*”, FrancoAngeli, Milan.

Mesarovic M., Macko D, Takahara Y., (1970), “*Theory of hierarchical, multi-level systems*” Academic Press.

Monge P. R., Contractor N. S., (2003), “*Theories of Communication Networks*”, Oxford University Press, NY.

Moyaux T., Chaib-draa B., D’Amours S., (2006,“Supply chain management and multiagent systems: An overview,” in Chaib-draa B, Müller J. P. (eds.), *Multiagent based Supply Chain Management*. Springer.

Paoloucci M., Sacile R., (2005), “Agent-based manufacturing and control systems,” CRC Press.

Saccani C., (1996) “Il Sistema Olonico,” *Sistemi&Impresa*, 2: 29-45.

Shen W., (2002) “Distributed manufacturing scheduling using intelligent agents,” *IEEE Intelligent Systems*, 17(1): 88-94.

Sherman, H. and Shultz, R., (1998), “*Open Boundaries: Creating Business Innovation through Complexity”*, Perseus Books, Boston (MA).

Smarr L., (1985) “An approach to complexity: numerical computations”. *Science*, 228:403–408.

Toffler A. (1980), “The third wave,” Bantam, New York (NY).

Stafford Beer A. *, (1972),“Brain of the Firm”*, The Penguin Press, London.

Stafford Beer A., 1985,*“Diagnosing the System for Organisations”*, Wiley Chichester

Stafford Beer A., 1979, *“The Heart of Enterprise”*, Wiley Chichester

Ulieru M., Cobzaru M., (2005) “Building holonic supply chain management systems: An e-logistics application for the telephone manufacturing industry”, *IEEE Transactions on Industrial Informatics* 1 (1): 18-30.

Valckenaers P., Bonneville E., Brussel H. V., Bongaerts L., Wyns J., (1994) “Results of the holonic control system benchmark at the kuleven,” Proceedings of CIMAT, pp. 128-133.

Volberda H. W., Lewin A. Y., (2003), “Co-evolutionary Dynamics Within and Between Firms: From Evolution to Co-evolution”, *Journal of Management Studies*, 40 (8): 2111-2136.