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Understanding Supply Chain Complexity with Performance Measurement

Anna C. Cagliano*. Antonio Carlin**
Carlo Rafele***

Department of Production Systems and Business Economics, Politecnico di Torino, Torino, Italy

** Tel: +39 0110907206; e-mail: anna.cagliano@polito.it*
***Tel: +39 0110907249; e-mail: antonio.carlin@polito.it*
**** Tel: +39 0110907286; e-mail: carlo.rafele@polito.it*

Abstract: Despite the great number of complex systems existing in the real world, complexity is currently a poorly explored topic. In organizational settings, managers regularly apply to complex contexts classical approaches developed for simple systems, just because they do not know how to take into account companies' internal and external complexity. Nevertheless, before developing new managerial models, a deep knowledge about drivers and effects of complexity is needed.

After defining the characteristics making supply chains complex systems, this paper discusses performance measurement as a methodology to analyze the effects of complexity on supply chain behavior. The results of a survey highlight that manufacturing companies usually evaluate isolated aspects of their supply chains, without considering the relationships between different performance indicators or dimensions. This work suggests System Dynamics as a valuable approach to understand the cause and effect connections among metrics and system elements affecting their values, thus clarifying the structure leading to a complex behavior.

This research is the first step of a larger project aimed at providing companies with innovative tools to understand and manage supply chain complexity.

Keywords: Complex Systems, Supply Chains, Performance Evaluation, System Analysis, System Dynamics

1. INTRODUCTION

Most of the systems people interact with are complex. Human beings themselves are complex, and human brain is the most complex system presently known (Gandolfi, 1999). However, despite the numerous authors that have tackled this issue under different perspectives (Laszlo, 1986; Gleick, 1987; Casti, 1989; Merry, 1995), knowledge about complexity is still lacking.

Also companies are no more simple systems operating in simple environments, where the organization itself regulates a big mechanism made up of replaceable employees, acting in a predictable way, and completely independent activities (De Toni and Comello, 2005). Instead, complexity is evident both inside and outside an organization. According to Daft (1992), internal complexity is given by the number of subsystems within an organization. To be more specific, he distinguishes between *vertical complexity*, the number of hierarchical levels, *horizontal complexity*, the number of organizational units, and *spatial complexity*, the number of geographical places where the organization is located. Scott (1992) defines external complexity as the different elements an organization simultaneously faces with. In general, a company deals with three kinds of external complexity: *environmental*, *managerial*, and *transactional*. The first one concerns exogenous changes, which are very quick, unpredictable, and often lead to instable situations. The second involves more unpredictable tasks and fewer feedbacks about managerial actions. Finally, the third is given by uncertainty, vagueness and interdependence of a company's internal and external transactions (Pilati, 1991).

Clearly, classical managerial models are no more applicable to this context. As a matter of fact, they are based on strict prescriptions, formalized control, and hierarchical authority, aiming to simplify an organization's activities and give definite solutions, but their approach does not take into account variability and uncertainty. Nevertheless, traditional managerial models are still successful among organizations, not because they are able to deal with complexity, but since managers do not know how to modify them to keep up with this emerging characteristic (Ashmos et al., 2002).

However, the development of new managerial paradigms requires a deep understanding of what drives complexity and of its consequences on organizational behavior.

This paper proposes performance measurement as a powerful tool to capture the effects of complexity on supply chain behavior in the manufacturing domain. Moreover, by analyzing the causes determining the values of specific indicators, it is also possible to get a sense of the drivers of complexity, and set corrective actions to keep it as low as possible. The work also suggests the use of System Dynamics to study cause and effect relationships among performance indicators evaluated both in one and in multiple supply chain echelons, thus allowing to get a deep understanding of the system structure giving a certain level of complexity.

The remainder of the paper is organized as follows. The definition of a complex system and the reasons why supply chains may be regarded as Complex Adaptive Systems are discussed in section 2. Section 3 introduces performance measurement, whereas section 4 details the results of a survey aimed at evaluating how companies are presently using performance indicators to deal with their complexity. Section 5 suggests the integration between performance measurement and System Dynamics to deepen the knowledge of the relationships among system elements through the analysis of the connections among different performance metrics. Finally, conclusions and issues for future research are given in section 6.

2. COMPLEXITY AND SUPPLY CHAINS

Before discussing the main characteristics making supply chains complex, it is worth spending some words on what defines a complex system. A unique definition of a complex system has not been developed yet, but numerous contributions, each of them highlighting different aspects, can be found in literature. De Toni and Comello (2005) name complex all those systems and phenomena made up of many components or agents interacting in infinite ways, and whose behavior is not given by summing up the behaviors of their constituent elements, but it is highly dependent on interactions. According to Ottimo (2003), a complex system is a system with a large number of elements, building blocks or agents, capable of exchanging stimuli with one another and with their environment. Sussman (2005) addresses the uncertainty about complex systems: a system is complex when it is composed of a group of related units (subsystems) for which the degree and nature of the relationships are imperfectly known. Some authors also talk about dynamic complexity, which arises because systems are dynamic, tightly coupled, governed by feedback, non linear, history-dependent, self-organizing, adaptive, counterintuitive, policy resistant, and characterized by trade-offs (Senge, 1990; Sterman, 2000).
Despite the diverse perspectives about complexity, what comes out is that a complex system is made up of many and different elements, linked by many and non linear relationships. This will be the basis for the discussion about the use of performance measurement to understand supply chain complexity.

Supply chains may be regarded as a special kind of complex systems, named Complex Adaptive Systems (CASs). CASs are open systems compounded by numerous elements interacting in a non linear way and forming a single, organized and dynamic entity able to evolve and adapt itself to the environment, without any singular element deliberately managing or controlling it (Holland, 1995; Gandolfi, 1999). Whereas Choi et al.(2001) formally discuss the reasons why supply networks are CASs, in this paper a more intuitive explanation will be given. First of all, a supply chain is open since it communicates with the external environment, such as the other supply chains it is connected to, thus forming a network more than a linear structure. Moreover, a supply chain is constituted by a large number of different elements: customers, suppliers, products, managers, employees, means of transport, other equipment supporting logistics activities, logistics providers and so on. All of them are usually linked by non linear relationships. A sort of cohesion among components also exists and this makes supply chains unitary entities. Since they coordinate human, material and financial resources towards a specific goal, moving parts through a value chain, it can be concluded that they are organized systems. A supply chain is also characterized by dynamic variables and is able to evolve and adapt itself to changes in the environment. For instance, it has to be extremely flexible to satisfy the ever new requirements of both customers and manufacturing systems. Two meaningful examples can be mentioned. In today's marketplaces the value is shifting towards adding service dimensions to product features, and firms are modifying their supply chain operations to pursue differentiation strategies. In addition, Just in Time philosophy recommends producing only what is necessary and when it is necessary, reducing waste and consequently the level of stock. Thus, logistics departments, which are an important component of a supply chain, have been obliged to increase their mix and volume flexibility to achieve small batch sizes and therefore fast throughput and short delivery lead times (Rafele and Cagliano, 2007).

3. PERFORMANCE MEASUREMENT TO UNDERSTAND SUPPLY CHAIN COMPLEXITY

Even if monitoring performance indicators is a way to translate the complex reality of a system into symbols that can be easily communicated, literature has scarcely considered this practice as a mean to deal with complexity. Nevertheless, a relationship between the definition of a complex system and the development of performance measurement in the last two decades can be established.

The need for supplementing traditional accounting measures with non financial metrics that came out in the 1980s and the early 1990s is a first attempt to observe the behaviour of the multiple components of a supply chain. Several dimensions are taken into account by authors, besides economic and financial performances. For instance, Beamon (1999) considers Resources, Output and Flexibility. Resources refer to inventory, personnel, equipment, energy and costs. Output mainly includes customer responsiveness and quality, whereas flexibility measures the ability of a system to support volume and schedule fluctuations from suppliers, manufacturers, and customers. Caplice and Sheffi (1994) look at logistics systems and supply chains as transformational processes whose main aspects can be captured by three performance dimensions: utilization, productivity, and effectiveness. The first one is a measure of input usage, the second tracks transformational efficiency, and the third monitors the quality of process output. Lockamy and Cox (1994) developed a framework measuring the performances of the most important supply chain functions and grouping them in three categories. Customer contains

marketing, sales and field services functions, Resource is made up of production, purchasing, design engineering and transportation functions, and Finance refers to the economic/financial function. Finally, English et al. (1999) suggests Financial, Quality and Resource as the dimensions able to give a global picture of the behaviour of supply chain support functions. As a matter of fact, financial measures evaluate short and long-term profits to insure a strong financial position, quality indicators assess the ability of an organization to meet the demand of both external and internal customers, and resource metrics balance the other two aspects with the output of production and/or service processes.
Besides these examples, other well-known performance measurement frameworks are designed to take into account the different elements of a supply chain. The SCOR model (Supply Chain Council, 2006) achieves this goal by evaluating performance for each main manufacturing and logistics process: Plan, Source, Make, Deliver and Return. The Balanced Scorecard (Kaplan and Norton, 1996) and the Performance Prism (Neely et al., 2002) take another perspective and assess supply chain performance from the point of view of the most important stakeholders, such as investors, customers, suppliers, employees, and regulators.

As it can be easily understood, even if this is not their main purpose, traditional performance measurement models are able to evaluate the effects of complexity on the behaviour of the many and different supply chain elements. Thus, they capture the first part of the general definition of a complex system. Nevertheless, there is a substantial lack of frameworks assessing the links between the performances of supply chain components, allowing studying non linear relationships among system elements. Despite the first attempts to evaluate the performances of supply chains as a whole, and not only of their single echelons (Brewer and Speh, 2000; Bullinger et al., 2002), a lot of work still need to be done. In particular, starting from current models, the mutual influences among both performance dimensions and single indicators have to be investigated through the analysis of the system structure giving the behavior reflected by metrics. A deep knowledge of this last makes performance evaluation a mean to understand not only the effects of complexity, but also its causes.

4. HOW ARE COMPANIES DEALING WITH SUPPLY CHAIN COMPLEXITY?

The goal of this section is detailing the results of a survey aiming to learn how companies are using performance measurement to capture the complexity of their supply chains. A representative sample of both Italian and international companies, operating in very diverse contexts, has been selected, and a reference framework has been used to classify the supply chain metrics they are currently monitoring. For confidentiality reasons, the names of these organizations will not be mentioned, but it can be reported that they have been divided into three main segments: *distribution companies* (some analyzed firms in this set operate in the apparel, cosmetics, and automotive spare part sectors), *manufacturing companies* (operating for instance in the automotive and avionic sectors), and *service companies* (among them transportation companies and providers of services for the manufacturing sector).

4.1 The Reference Framework: LogistiQual Model

The performance measurement dashboards adopted by the analyzed companies were compared against a consolidated model for the evaluation of operational activities at a single organization. LogistiQual (Rafele, 2004; Grimaldi and Rafele, 2007) gives a complete understanding of the quality level of logistics and supply chain service through three dimensions, namely *Tangible Components*, including physical resources and personnel that allow a company to fulfil customers' needs, *Ways of Fulfilment*, looking at how the service is delivered to customers, and *Informative Actions*, integrating the other two macro-classes by analyzing communication with customers, and emphasizing the importance of timely and complete information. Each of the three macro – classes is divided into some classes inside which single performance indicators can be placed, according to the process under consideration (Fig.1). The framework can be applied to both suppliers' performances (*Source – LogistiQual*) and internal and towards customers ones (*Self-LogistiQual*). Also, it has been extensively validated by both applying it to multiple manufacturing and service settings and comparing the model with a theoretical company represented by the business process classification proposed by SCOR model (Grimaldi and Rafele, 2007).

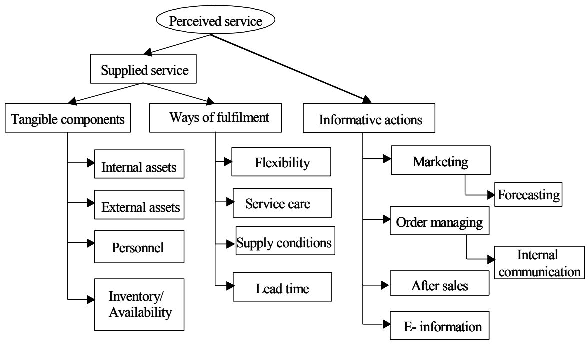

Fig.1. LogistiQual model.

4.2 Survey Outcomes

As a first consideration, the investigated companies measure isolated aspects of their supply chain complexity and do not take into account the connections between different supply chain components and their related indicators. In this way, like mainstream research, they use performance measurement to tackle a complex system only from the point of view of its single parts. Moreover, many organizations do not have a thorough picture of performance, since they neglect important elements determining the level of service perceived by internal and external customers.

Companies tend not to pay attention to the effects of complexity on their suppliers' behavior (Source – LogistiQual). In some cases suppliers are not evaluated at all, and, where they are, the three macro-classes of the model are not equally represented. Only a 30% of the surveyed companies, mainly in the distribution and service segments, use indicators belonging to the Tangible Components category, highlighting that this type of performance is often perceived as a matter of suppliers. However, the way of managing physical assets, personnel and inventory indirectly affects the service delivered to downstream supply chain echelons and, in turn, their operations. For instance, a poor inventory policy for a raw material may lead to frequent stockouts determining uncertainty in the customer's production lead time and enhancing supply chain complexity. On the other hand, companies that outsourced a big portion of their manufacturing and logistics processes face a higher complexity given by the increased number of supply chain actors and relationships. In this situation, metrics about tangible components were found to be of paramount importance for monitoring the level of service of strategic partners. All the companies assessing suppliers' performance use metrics belonging to the LogistiQual dimension Ways of Fulfillment, regardless of the segment. The great attention to this macro-class (it is usually formed by more than 50% of the indicators adopted by an organization) is due to the fact that it represents the more evident supplier outcomes that can be easily quantified and linked to internal customer processes. Most of the indicators can be placed into the model class Service Care, which basically addresses the effects of complexity on time and quality. However, their nature is strictly dependent on the particular context. In fact, certain companies measure timeliness, correctness, reliability and damages, whereas others only focus on a couple of them, such as correctness and reliability or reliability and damages. It is interesting to point out that timeliness is not always assessed, despite its relevance to supplier evaluation. As far as flexibility indicators are concerned, sometimes they are not able to capture suppliers' ability to adapt themselves to different customer needs, thus neglecting one of the main characteristics of a complex adaptive system. For instance, some metrics assess the number of urgent or special orders that have been fulfilled in a period without comparing them with the number of urgent or special orders that have been issued. Finally, measures belonging to the LogistiQual class Lead Time show that companies consider delays and time variability as primary consequences of a high level of vertical, horizontal and spatial complexity. The survey highlighted a scarce attention towards monitoring the level of communication with suppliers (LogistiQual macro-class Informative Actions). Only 20%-25% of the total number of metrics evaluated by a company can usually be included in this category. However, a good level of information helps reducing complexity by increasing the understanding on the functioning of the various elements of a system and their connections. In both manufacturing, and distribution, and service settings, the most represented classes are Order Managing and After Sales, whereas Internal Communication, that is how the information about orders and working procedures is shared within the supplier's organization, is often neglected, since management is more interested in the informational flow between suppliers and external actors. In addition, informative systems decrease the uncertainty inherent in complexity enabling a timely communication among all the levels of a firm and among supply chain echelons as well. Nevertheless, the still limited diffusion of informative systems, especially in small and medium enterprises, makes the assessment of their performance not so common among the analyzed companies.

All the studied organizations recognize the necessity to measure the effects of complexity related to internal processes and those involving customers (Self – LogistiQual), but they do that at various levels of detail. The macro-class Tangible Components is quite well represented. Some firms, mainly in the distribution and service segments, undertake a deep analysis being also interested in the productivity and efficiency of physical means supporting logistics activities, while the total absence of indicators belonging to the class Internal Assets is the main shortcoming of some performance dashboards, particularly in the manufacturing segment. A complex system is made up of people, and their behavior is perhaps the more evident manifestation of complexity. To this end, performance about personnel is evaluated by a great variety of metrics, according to the specific level of work automation. This is more evident in the companies belonging to the distribution segment, where the personnel taking care of logistics activities often play a crucial role. The investigated performance measurement systems also include many metrics that can be classified into the model class Inventory/Availability. Looking at LogistiQual macro – class Ways of Fulfilment, Service Care is once again the most populated class, together with Lead Time. Tracking the ability and readiness to react to changes in customer requirements (flexibility) has not been considered as fundamental by the surveyed organizations. For the macro-class Informative Actions similar remarks as for the supplier evaluation can be made.

Besides studying indicators, the survey also investigated if their values are subjected to a formal review and analysis, figuring out the reasons for them and the corrective actions to bring each performance towards its target value. In many cases companies simply collect numbers without further working on them to discover the causes of a particular behavior.

5. STUDYING SUPPLY CHAIN COMPLEXITY WITH SYSTEM DYNAMICS

Literature review and the survey highlighted the inability of performance measurement to understand the relationships between different supply chain components through the study of the connections among indicators. Moreover, companies usually perform a poor analysis of the metric values in order to identify drivers of complexity. In this section performance measurement will be integrated with System Dynamics methodology to overcome these shortcomings.

5.1 Quick Introduction to System Dynamics

System Dynamics (SD) is an approach for analyzing the behavior of complex and dynamic social, technological, economic and political systems, representing them by means of stocks, flows and interacting feedback loops. It has been introduced by Forrester (1961) at MIT, and further developed by Sterman from the 1980s. SD uses qualitative and quantitative models to understand how structure produces system behavior and to derive knowledge to predict the consequences over time of changes in system policies. SD bases heavily on the description and quantification of cause and effect relationships between variables, since it is through their interactions that system behavior emerges. The reader may refer to Sterman (2000) for detailed information about this methodology. Here the discussion will be focused on its application to supply chain complexity. Its peculiar characteristics make SD particularly suitable to study complexity. In this paper it will be used as a tool for complexity control, in order to understand supply chains as complex systems, control them and allowing the analysis of the consequences of selected strategies.

5.2 Understanding Causes of Complexity and Relationships among Supply Chain Components

The first step in integrating performance measurement with SD to study supply chain complexity is identifying the main system quantities and the connections among them. This understanding is formalized by sketching Causal Loop Diagrams (CLDs), which show feedback loops among variables, besides their cause and effect relationships. In this way, the system structure has been captured and every behavior may be explained in terms of the interactions among key quantities. The last will be also linked to the definitions of indicators assessing system performances, allowing easily detecting what determines their values. Every supply chain component could then be seen as a system and described in terms of relationships among its main quantities and performance measures. Through this approach, the study of the mutual influences among indicators evaluating the performance of different supply chain components will reveal the non linear relationships and the feedback loops among these parts contributing to a certain level of complexity.

CLDs are qualitative in nature, therefore, in order to perform a quantitative analysis, they need to be translated into Stock and Flow Diagrams, and the mathematical equations defining connections among quantities have to be derived. After validating the resulting model, simulation will give time evolutions of the quantities and relationships under consideration. In order to show how this approach works, an example taken from a real case (Rafele and Cagliano, 2007) will be described. For the sake of simplicity, only a qualitative study using CLDs will be detailed.

A medium-sized Italian company producing injection molded plastic parts for cars manufactures door trim panels. These are made from four components. The example focuses on a purchased one, a fixing clip that will be named A. Two parts of the supply chain of the panels are studied with System Dynamics: A order management, the interface with the supplier, and A inventory management, a focus company's internal process. Their structures, together with key quantities and the relationships among them, are represented by the CLDs in fig.2 and fig.3, where P stands for panel and w for all the other finished products manufactured from component A. The Order Fulfilment Efficiency (OFE) of the supplier of A is the performance metric chosen for the first system, whereas the Inventory Availability of A (IA) is the one selected for the second. OFE is defined as the quantity of A delivered in a period over the quantity of that item on order in the same period. IA is the ratio between the inventory level of A during a period and the required quantity of that item in the same period. Assuming that A Shipment Rate is equal to A Arrival Rate (no unit of A gets lost during transportation), the analysis of CLDs reveals that A Shipment Rate influences A Inventory Entry Rate (Fig. 2), which in turn determines A Inventory (Fig. 3). But, basing on the definitions of the two indicators, A Shipment Rate in a given time bucket returns the quantity of A delivered in that period, thus contributing to give OFE, and A Inventory determines the value of IA. Thus, since A Shipment Rate may be expressed as a function of OFE, the Order Fulfillment Efficiency of the supplier of A influences the inventory availability of this component at the focus company.

This simple example highlights how SD is able to make clear the connections between supply chain components, which could be not so evident from a process mapping with traditional tools like flow charts. This point is enhanced by the fact that the connections can be put in mathematical terms by equations forming the quantitative model. Furthermore, links among indicators and system quantities are formalized, allowing a quick understanding of root causes of performances.

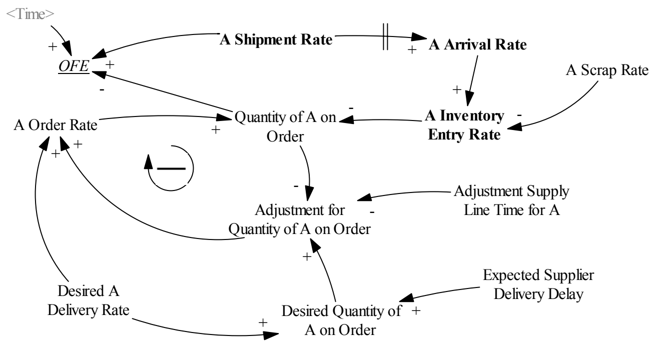

Fig.2. A order management.

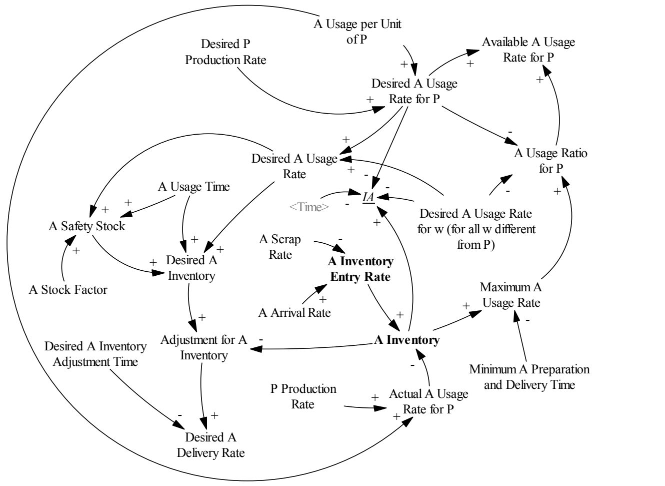

Fig.3. A inventory management.

6. CONCLUSIONS

Despite the increasing awareness about complexity of supply chains, and broadly speaking of organizations, there is a strong need for developing new managerial approaches able to capture it. Of course, achieving this goal requires understanding in depth causes and effects of complexity. Nevertheless, literature usually tackles complexity from a general point view, without considering how it appears in specific contexts.

The paper contributes to fill the gap by proposing performance measurement as an approach to detect the effects of complexity on supply chain behavior. Literature review and a survey highlighted that, even if performance evaluation is able to address the multiple and different components of a supply chain, it does not allow to study the non linear relationships among them. To this end, the authors suggest to integrate it with System Dynamics, a simulation methodology analyzing the cause and effect relationships among system variables. Making possible to represent the system structure giving a certain behavior, System Dynamics is valuable to understand also causes of complexity.

This research is intended to be an explorative study with the purpose of highlighting the shortcomings of the present way of addressing supply chain complexity, and proposing possible solutions. A deep knowledge about drivers and consequences of supply chain complexity is the basis for developing managerial approaches allowing companies to control complexity. To achieve this research goal, general complexity theory principles should be adapted to reflect supply chain characteristics. For instance, it could be interesting to determine which practical situations make a logistics process be in one of the three states characterizing a complex system (ordered, chaotic, or complex). In addition, it should be studied how operational complexity, investigated by the approach proposed in this work, impacts on financial outcomes. For this purpose, after extending LogistiQual to include economic/financial performance as well, System Dynamics methodology could be again a valuable tool.

REFERENCES

Ashmos, D.P., Duchon, D., McDaniel, R.R., and Huonker, J.W. (2002). What a mess! Participation as a simple managerial rule to “complexify” organizations. *J. of Management Studies,* 39 (2), 189-206.

Beamon, B.M. (1999). Measuring supply chain performance. *Int. J. of Op. & Prod. Mng,* 19 (3), 275-292.

Brewer, P.C. and Speh, T. W. (2000). Using the Balanced Scorecard to measure supply chain performance. *J. of Business Logistics*, 21(1), 75-93.

Bullinger, H-J., Kuhner, M., and Van Hoof, A. (2002). Analysing supply chain performance using a balanced measurement method. *Int. J. of Production Research*, 40 (15), 3533-3543.

Caplice, C. and Sheffi, Y. (1994). A review and evaluation of logistics metrics. *The Int. J. of Logistics Management*, 5(2), 11-28.

Casti, J. L. (1989). *Paradigms lost*. Avon Books, New York.

Choi, T.Y., Dooley, K.J., and Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. *J. of Op. Mng.,*19, 351-366.

Daft, R. L. (1992). *Organization theory and design*. West Publishing, St Paul.

De Toni, A. F. and Comello, L. (2005). *Prede o ragni. Uomini e organizzazioni nella ragnatela della complessità*. Utet Libreria, Torino, Italy.

English, J.R., Mendoza, A., and Watson, J. (1999). Quality monitoring of logistics systems. Draft publication.

Forrester, J.W. (1961). *Industrial dynamics*. The MIT Press, Cambridge, MA.

Gandolfi, A. (1999). *Formicai, imperi, cervelli. Introduzione alla scienza della complessità*. Bollati Boringhieri Editore, Torino, Italy.

Gleick, J. (1987). *Chaos*. Viking Penguin, New York.

Grimaldi, S. and Rafele, C. (2007). Current applications of a reference framework for the supply chain performance measurement. *Int. J. of Business Performance Measurement*, 9(2), 206 – 225.

Holland, J.H. (1995). *Hidden order*. Addison-Wesley, Reading, MA.

Kaplan, R.S. and Norton, D.P. (1996). *The Balanced Scorecard - Translating strategy into action*. Harvard Business School Press, Boston, MA.

Laszlo, E. (1986). *Evoluzione*. Feltrinelli, Milano, Italy.

Lockamy, A. and Cox, J. (1994). *Reengineering performance measurement*. Irwin Professional Publishing, New York.

Merry, U. (1995). *Coping with uncertainty*. Praeger, Westport, Ct.

Neely, A., Adams, A., and Kennerley, M. (2002). *The Performance Prism. The scorecard for measuring and managing business success.* Prentice Hall, London.

Ottimo, M. (2003). Complex systems. *AIChE Journal,* 49(2), 292-299.

Pilati, M. (1991). La complessità nella relazione tra proprietà e management. In Colombo, G., *Complessità e managerialità. Cambiamenti di scenario e nuovi assetti d'impresa*. EGEA, Milan, Italy.

Rafele, C. (2004). Logistic service measurement: a reference framework. *J. of Manufacturing Technology Mng*, 15(3), 280-290.

Rafele, C. and Cagliano, A.C. (2007). A tool for managing complexity in logistic systems under mass customization. In Blecker, T., Edwards, K., Hvam, L., Friedrich, G., and Salvador, F.(ed.), *Innovative processes and products for mass customization*, 293-308. GITO-Verlag, Berlin.

Scott, W.R. (1992). *Organizations: rational, natural and open systems*. Cliffs, Prentice-Hall, Englewood.

Senge, P.N. (1990). *Fifth discipline: mastering the five practices of the learning organization*. Doubleday, New York.

Sterman, J.D. (2000). *Business Dynamics: systems thinking and modeling for a complex world*. Mc-Graw Hill, Chicago.

Supply Chain Council (2006). SCOR 8.0 Overview, available at: www.supply-chain.org (accessed April 17, 2008).

Sussman, J.M. (2005). *Perspectives on intelligent transportation systems*. Springer, New York.