Chapter 5
Conceptual Framework of Supply Chain Competition Based on a System of Systems Approach

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Abstract System of Systems (SoS) paradigm has been extensively applied to a wide variety of fields. In recent years, some works have shown that the supply chain can be conceptualized as a SoS, yet they do not consider market competition among supply chains. We develop a competitive supply chain SoS framework that extends existing approaches to incorporate multi-chain market competition, yielding an illustrative case of an uncommon SoS with competitive constituents. While satisfaction of customer needs in a certain market is a key objective for supply chain management, it is only achieved by the set of competitive supply chains.

Keywords System of Systems · Supply chain management · Supply chain competition

5.1 Introduction

Since the beginning of the century, there has been a growing interest in the development and application of the System of Systems (SoS) paradigm to different fields [12, 29]. The development of the systems approach traces back almost a century when in 1926 Smuts introduced "holons" from a nature point of view and broadened the idea of a "whole that is more than the sum of its parts" [3, 43]. Von Bertalanffy [47] extended this concept and developed the grounds of the general system theory. Regarding the current System of Systems approach, we can underline the work of Ackoff [1] as a milestone. Ackoff [1] organizes and gives coherence to previous knowledge on the conceptualization of a system; at the same time, the author provides

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a reference framework through a set of basic definitions, starting with “a system is a set of interrelated elements.” A system composed of other systems arises naturally in this framework, although, for a set of systems to become a SoS, additional features and behaviors are required.

Jaradat et al. [29] provide a historical approach to SoS. Through the study of hundreds of sources, the authors define the main stages in the development of the SoS concept and review its main characteristics. The general concept of a SoS is approached as follows: “At a most basic level, SoS is concerned with the integration and coordination of multiple autonomous systems, considered as a unity, that functions to achieve performance, purpose or behavior that none of the individual constituent systems is capable of independently” [29].

Several definitions of SoS have been proposed, as well as several attempts to identify the distinguishing features of a SoS [4, 19, 24, 29, 30]. Of particular importance is the so-called ABCDE characterization proposed by Boardman and Sauser [8]. It is the result of a comprehensive review of the literature and the analysis of more than 40 SoS definitions, producing a set of five main features of the constituent systems [8, 24]: *Autonomy* refers to the freedom of the constituent systems to set and follow their goals under some restrictions but without being subject to external control; *belonging* (B) refers to the voluntary decision of the constituent systems to take part in the SoS; *connectivity* (C) refers to the ability of the constituent systems to dynamically establish links among them, typically forming a network-based architecture; *diversity* (D) refers to the variety of the SoS capability compared to the requirements-driven functionality of the systems; *emergence* (E) refers to the capability of a SoS to show unforeseeable behavior, evolve and adapt dynamically to new conditions in ways that are not the result of a previous design. Boardman and Sauser [8] emphasize the differentiation between a system of subsystems and a SoS. Characterization is further developed in Gorod et al. [24], with a detailed historical path to the development of the concept of SoS from an engineering point of view, as well as a confrontation with the systems engineering paradigm. Different types of SoS can be identified depending on how much the constituent systems fit into the profile of each SoS defining characteristic.

The standard conceptualization of a supply chain is a network of “all the parties involved, directly or indirectly, in fulfilling a customer request” [15]. These parties include suppliers, manufacturers, distributors, warehousers and retailers. Over the last few years, some authors have shown the applicability of System of Systems to supply chain management (SCM) [11, 14, 28, 32]. The supply chain is formed by a set of independent systems (*autonomy*), each one with its own purpose that aims to jointly achieve a supra-purpose: the satisfaction of customer needs (*belonging*). The systems dynamically create a network that evolves according to the global objectives and through the expanding possibilities of technology (*connectivity*) to offer an increasing variety of products and services (*diversity*) while adapting to a changing environment and varying customer needs (*emergence*). From the viewpoint of some of the ABCDE characteristics, clearly a generic supply chain falls into the SoS profile (*autonomy*, *belonging*, *emergence*), whereas some of the characteristics also show behavior that is partly characteristic of a system composed of subsystems (*connectivity*, *diversity*).

Although there are several works that justify the conceptualization of a supply chain as a SoS, we identify an existing gap in the literature: They do not consider the implications of multi-chain market competition. In this paper, we incorporate the results of the referred works within the framework of a SoS approach to SCM and propose to consider a new level of abstraction in the conceptualized system to include market competition among supply chains. The remainder of the chapter is organized as follows. In the second section, we summarize the existing SoS approaches to supply chain management. Then, in the third section the proposed conceptual framework of SoS approach to supply chain competition is developed. In the fourth section, the resulting system is characterized as a SoS, showing how it can describe relevant aspects of supply chain competition through the analysis of the ABCDE behavior. Finally, the main conclusions are summarized in Sect. 5.5.

5.2 Literature Review

Some authors have shown the applicability of the SoS paradigm to supply chain management (SCM) based on different SoS characterizations. A preliminary work of Hassan [26] delves into the conceptualization of the supply chain as a system composed of subsystems, posing some relevant considerations regarding the systems approach to the supply chain but without considering the specificities of the SoS behavior. Mastrocinque et al. [32] underline the intrinsic fit of some features of a supply chain to the concept of SoS based on the work of Bjelkemyr et al. [7] and show the interest in applying this paradigm to the design of a supply chain. Jaradat et al. [28] analyze the convergence of SoS attributes and the principles and concepts of SCM. The authors show how the SoS paradigm can complement SCM practices, placing particular emphasis on the satisfaction of customer needs through the integration and collaboration among supply chain participants. Choi et al. [14] demonstrate that the sustainable fashion supply chain (extendable to a supply chain in general) is a SoS based on ABCDE criteria. Bondar et al. [9] analyze the emergence behavior that is characteristic of SoS from the perspective of information systems architecture and present the collaborative concurrent engineering process in the automotive supply chain as an example of an agile SoS. Darabi et al. [18] propose a new approach to governance of a system specifically aimed at SoS and apply their proposal to a supply chain to illustrate the characteristics of the framework. Since the publication of the fundamental works of Christopher and Peck [16] and Sheffi [41], the topic of supply chain resilience has gained increasing attention [27, 36]. It is an issue that has also been addressed with an SoS approach. Bukowski [11] analyzes the dependability feature in SoS and presents a case of disruption in a supply chain as an illustrative example to demonstrate the influence of dependability on the resilience of the system.

Table 5.1 summarizes the applications of the SoS paradigm to the supply chain, including the criteria to characterize a supply chain as a SoS and the focus of the application. As aforementioned, none of the works consider the set of competitive supply chains when defining the System of Systems. Furthermore, there are few examples of

Table 5.1 Supply chain as a System of Systems

Author	SoS characterization	Supply chain focus
Mastrocinque et al. [32]	Evolutionary behavior, self-organization, heterogeneity, emergent behavior, small-world/scale-free networks [7]	SC design and optimization
Jaradat et al. [28]	Integration, interconnectivity, emergence, complexity, evolutionary development, ambiguity	SC vertical integration and collaboration
Choi et al. [14]	Autonomy, belonging, emergence, connectivity, diversity (ABCDE) [8]	Sustainable fashion SCM
Bondar et al. [9]	Information systems architecture with emergence behavior	SC emergence in concurrent engineering
Darabi et al. [18]	Purpose integration, belonging regulation, incentivizing device, interactions protocol, and principles dissemination and perception distortion	SC governance
Bukowski [11]	Multidimensional complexity, independence, emergence behavior, evolutionary development	SC resilience

competitive SoS. In the standard approach of a generic SoS, the constituent systems join the SoS and establish connections among them to collaborate in the pursuit of a supra-purpose. Thus, most of the previous works are focused on collaborative SoSs [4, 12]. The work of Darabi and Mansouri [19] is an exception and provides valuable insights into the roles of collaboration and competition in SoSs, studying its influence on the autonomy and belonging characteristics of the constituent systems. The study is supported by an experiment with an agent-based simulated system which shows the relevance of competition to autonomy and behavior when resources are scarce. Collaboration is established not only as a voluntary decision to achieve a mutual benefit but also as a necessity to continue belonging to the SoS.

We attempt to fulfill the identified gap in the literature with the proposal of a conceptual framework of competitive supply chain SoS, that, not only contributes from the supply chain management point of view, but also constitutes an illustrative example of a competitive SoS.

5.3 Development of the Proposed Framework

To develop the proposed framework, we use a bottom-up nested conceptual modeling approach, often referred to as a "Russian doll" approach [45], in which each model constitutes a part of a broader scope model. It has been applied to a wide variety of domains [20, 38].

As the starting point for the modeling process, we take the standard supply chain conceptualization as a SoS (Table 5.1) and complement it with the consideration of the trend toward SC 4.0 and the explicit characterization of the customers SoS (Sect. 3.1). Subsequently, the model is enhanced by widening the scope, under a SoS approach, to consider the whole competitive market in which different supply chains concur (Sect. 3.2).

5.3.1 Supply Chain 4.0 SoS

As mentioned above, the development of the framework takes the Supply Chain SoS (SC SoS) as the starting point of the conceptual modeling process and complements it taking a SoS approach to the Supply Chain 4.0 or digital supply chain. We identify three main SoSs as depicted in Fig. 5.1:

- **Supply Chain SoS**. It corresponds to the standard supply chain conceptualization as a network of agents involved in satisfying customer orders [15]. We represent the supply chain, excluding customers, as a simplified network of industrial nodes. As detailed in the introduction (Table 5.1), different authors show that the supply chain is a SoS based on a variety of criteria. SC SoS includes a constituent control SoS as described next.
- **Control SoS**. For a supply chain to be competitive nowadays, it is necessary to achieve an important level of coordination [15]. Panetto et al. [34] provide a framework for the application of the new technologies that are behind the so-called SCM 4.0 and propose the suitability of SoS as a reference to build a cyber network

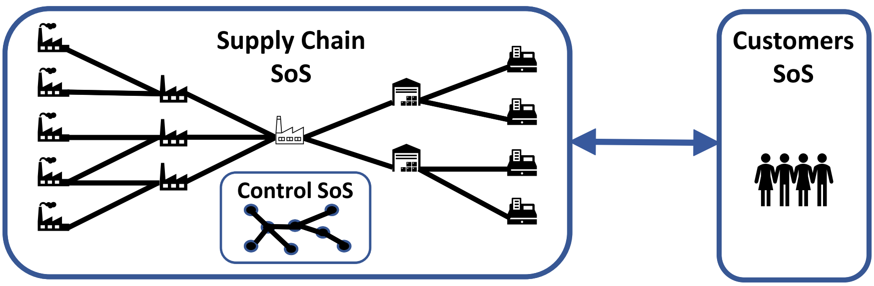

Fig. 5.1 Supply chain 4.0: System of Systems approach

of sensors and control systems that will enable SCM. Referring to the ABCDE SoS characterization, new technologies advocate for a decentralized network (C) of autonomous intelligent agents (A) that are loosely integrated so they can join or leave the system (B), thus providing the necessary resilience (D) while being able to adapt dynamically to changing conditions (E) [34]. Choi [13] outlines the applicability of the SoS approach to SCM that incorporates big data and related technologies. Therefore, we can include in each supply chain SoS a constituent controlling SoS that will evolve alongside digital technologies. The control SoS is schematically depicted as a network of lines connecting dots in Fig. 5.1.

- **Customers SoS**. Customers will form a social SoS as defined by Bar-Yam et al. [5]. Regarding the ABCDE characterization, the profile of the constituent systems (i.e., the customers) shows some characteristics that are directly aligned with a pure SoS, whereas others differ to some extent. It becomes evident that the customers are autonomous (A). Even though they do not group explicitly, their belonging is the result of individual interest, which in general aligns with the global purpose (satisfaction of their needs) (B). Since we are referring to customers of a specific supply chain, connectivity is only relevant in some cases in which customers use network communications to create a community (C). The constituent customers will share common facets and present a certain homogeneity, although they will be diverse in the sense that each individual is inherently unique (D). The group of customers will show some degree of emergence since their behavior can only be approximately predicted in the short term (E).

5.3.2 Supply Chain Competition: Competitive Supply Chain SoS

Stock and Boyer [44] analyze 173 definitions of supply chain management and propose the following definition that encompasses the main aspects and elements identified: "The management of a network of relationships within a firm and between interdependent organizations and business units consists of material suppliers, purchasing, production facilities, logistics, marketing and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies and achieving customer satisfaction." [44] Satisfying customers' needs is essential in the usual current conceptualization of SCM. However, it should be noted that in general, customers' needs are not satisfied by a single supply chain, but through the existence of a set of competitive supply chains that offers a variety of substitute products. This fact is stressed under the proposed conceptual model. In addition, supply chains compete for market share, and competition encourages the development of products that meet the needs and preferences of customers.

The core proposal of this work is to conceptualize supply chain competition based on a SoS approach. According to the "Russian doll" conceptual modeling approach

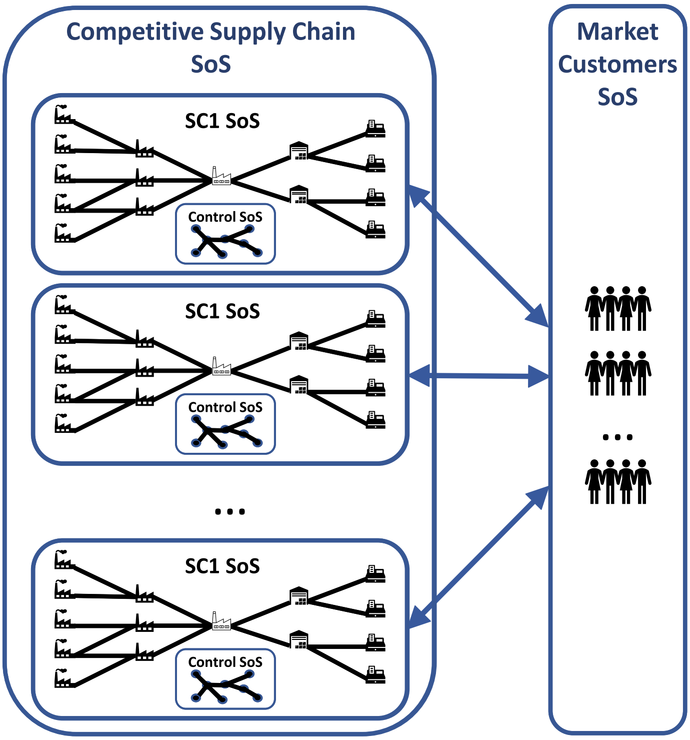

Fig. 5.2 Supply chain competition: System of Systems approach

adopted [45], we develop it as an evolution of the framework of Fig. 5.1, as depicted in Fig. 5.2, in which we can define two new SoSs:

- **Market Customers SoS**. Formed by all actual and potential customers of the market. Significantly, it fits better as a SoS according to the ABCDE characterization than the customer SoS of Fig. 5.1. Customers benefit from the fact of participating in a system closer to a SoS in terms of satisfaction of their needs. Connectivity in the market customers SoS is much more relevant than in the customer SoS (Fig. 5.1), with a direct effect in the *emergence* as some customers influence the market. Communication through social networks and opinions shared in Internet forums have grown enormously in recent years, becoming crucial to customer buying decisions in some sectors [37, 39, 46].
- **Competitive Supply Chain SoS**. Formed by the set of all supply chains that operate in a certain market. Each supply chain constitutes a SoS itself, as previously defined. Satisfaction of customers' needs acquires full sense as the supra-purpose of the competitive SC SoS. The competitive SC SoS illustrates the conceptual modeling process that starts from the Supply Chain 4.0 SoS and provides an explicit representation of supply chain competence through the interaction with the customers. However, the actual structure of the set of competitive supply chains

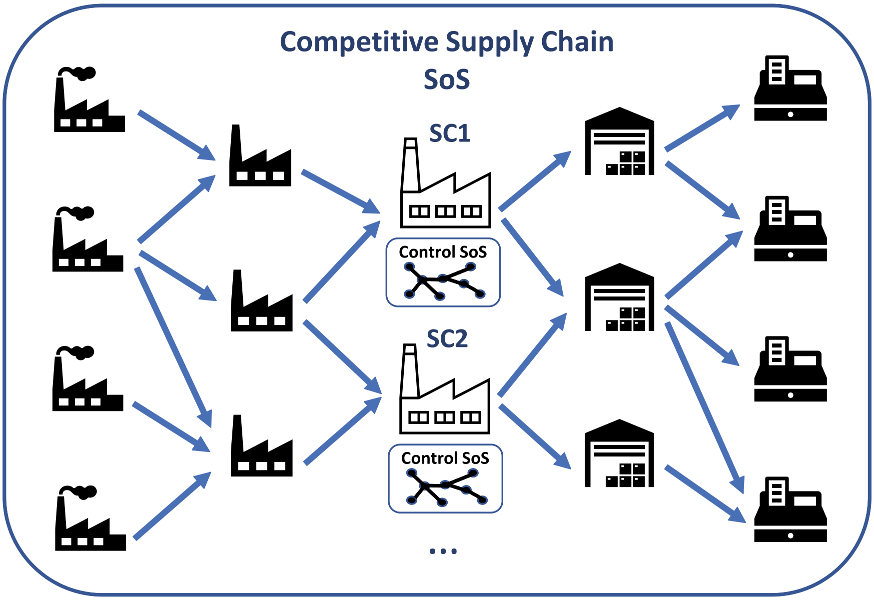

Fig. 5.3 Competitive Supply Chain SoS

is generally a very complex single network, with some of the nodes belonging to different supply chains. Figure 5.3 represents this single competitive SC SoS network. The characterization of this network as a SoS is analyzed in the following subsection.

5.4 Characterization of the Competitive Supply Chain as a SoS

We complete the proposal of a competitive supply chain framework with its characterization as a SoS. It is carried out on the basis of the ABCDE characterization and by paying special attention to the comparison with the single supply chain SoS (summarized in Table 5.2). In fact, it is shown that it fits in the SoS paradigm even better than the single supply chain.

- **Autonomy**. Clearly, in general, the constituent agents of the network of all competitive supply chains are autonomous and have managerial and operational independence [40]. The same applies to each supply chain [14], but it will be less applicable as the supply chain shows a high degree of vertical integration [25]. When a company encompasses many of the steps of the supply chain, the autonomy of the constituent systems is reduced. Even for a specific industry, we can find different autonomy behaviors among different supply chains, such is the case of the fashion

Table 5.2 ABCDE characteristics of the Competitive Supply Chain SoS versus single Supply Chain SoS

Criteria	Competitive supply chain SoS versus single supply chain SoS
Autonomy (A)	More proportion of independent constituent systems
Belonging (B)	More stable and stronger linkage of the constituent systems to the SoS
Connectivity (C)	Denser network structure and consideration of horizontal collaborations
Diversity (D)	Variety of products and drastic increment of resilience
Emergence (E)	Improvement of customer satisfaction and adaptation to changing markets

industry studied by Choi et al. [14] in which the case of H&M analyzed by the authors differs from its competitor Inditex-Zara [2, 21].

- **Belonging**. Constituent agents freely join other agents, establishing collaboration relationships, accepting the necessary rules and aligning their own purpose as autonomous systems to achieve the SoS supra-purpose of satisfying customer needs [40]. Since a company (supplier, manufacturer, distributor) can participate in multiple supply chains of a certain market, the belonging feature gains more meaning under the proposed competitive supply chain SoS framework than the single supply chain approach taken in the literature (Table 5.1). Companies can exercise their autonomy and abandon the SoS, but in general their linkage to the Competitive SC SoS is more stable than the commitment to a single supply chain. A supplier might break the relationship with some manufacturer—with a single supply chain—while maintaining its belonging to the Competitive SC SoS by delivering materials to other manufacturers (the same applies to a distributor).
- **Connectivity**. However connectivity is a feature of each supply chain considered as a SoS, it also gains relevance and stability in Competitive SC SoS, since, in general, there are more connections—that is, more suppliers and/or customers—per node, so the resulting network is much closer to the characteristic structure and behavior of the SoS [40]. Frequently, some suppliers deliver materials to competitor manufacturers, whereas some distributors will consolidate deliveries from competitor manufacturers. Since the practical expansion of computer network protocols and multi-tier architectures, information technologies have played an essential role in enabling efficient inter-company network consortiums [6]. The increasing role of technology and the trend toward Supply Chain 4.0 favor the efficacy and efficiency of multi-chain material flow [33]. On the other hand, and of particular relevance, the competitive SC SoS framework elicits another type of links that are receiving increasing importance: those among competitors at the same tier of the supply chain that lead to horizontal collaboration or cooperation [17, 23, 31]. Polenske [35] provides a formal distinction between collaboration and cooperation, followed by an in-depth analysis of the interrelation of the so-called 3C—collaboration–cooperation–competition. Although there is a variety of particular cases, and no generalization is possible, vertical relationships would be typical examples of collaboration, whereas horizontal relationships would be typical examples of cooperation. Another term is being increasingly used

to refer to relationships between firms that compete in their core processes, while cooperating in non-core processes: coopetition [48, 50].

- **Diversity**. Diversity "is a necessary condition for making the overall SoS resilient" [10]. As mentioned in the introduction, the SoS approach to the supply chain is particularly well suited to analyze the dynamics of supply chain disruptions and, consequently, the design for resilience [11]. It is noteworthy that the consideration of the set of competitive supply chains leads to a highly relevant shift in terms of the diversity provided by the SC SoS. The evolving variety of competitive products offered in the market not only reflects better customer needs satisfaction, but it is also the key to overcome supply chain disruptions from the customer's perspective. If a disruption affects a specific supply chain, competitors can fulfill market demand until the affected supply chain recovers from the disruption. If they cannot wait until the recovery, some of the customers will find the alternative products as a temporary solution, whereas others might even change their preferences in the absence of the product usually acquired. When the disruption has a global effect, such as in the case of natural disasters, transportation strikes, political disorders or a pandemic such as COVID-19, and all competitive supply chains in a certain market are affected, the impact will generally be drastically mitigated by the set of competitive supply chains compared to a single supply chain. The time during which there is no product of a certain market available is drastically reduced.
- **Emergence**. This feature is significantly more present in the competitive SC SoS than in the single SC SoS. On many occasions, the changing market and/or irruption of new technologies force some competitors to abandon the market leading pace to others. It is the adapting nature of the competitive SC SoS that makes it possible to evolve alongside with the market and provide the customers with the products they demand. On the other hand, when faced with global disruptions, the offer of new substitutive products and the alternatives identified by the set of competitive supply chains will mitigate the effect for customers. Sheffi describes numerous examples of innovative successful alternatives that companies developed in response to the COVID-19 pandemic [42].

5.5 Conclusions

The study of literature shows that a single supply chain constitutes a System of Systems (SoS), although there has been no attempt to conceptualize the system formed by the set of market competitor supply chains. We show how the System of Systems (SoS) approach can be applied to conceptualize this set of competitor supply chains and that the resulting competitive supply chain SoS fits as an SoS better than a single supply chain according to the autonomy, belonging, connectivity, diversity and emergence (ABCDE) characterization. On the other hand, the SoS thus defined constitutes an illustrative example of competitive SoS.

The analysis of the different SoS aspects shows that it can be applied to describe supply chain market competition dynamics. Specifically, it elicits the fact that customer needs are satisfied not by a single supply chain but by the set of competitive supply chains. The analysis of the SoS allows to characterize supply chain resilience issues as well as to identify ways of improving its performance. With this regard, the role of collaboration among market competitors appears as a promising aspect to be studied in order to systematically find ways of global performance improvement.

The proposed framework can incorporate open-loop supply chains when the material flows are handled by companies of one sector. It can be expanded with the interaction of external systems to model the generic circular supply chain [22] and complement existing conceptualizations [49].

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