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The Complementary Perspective of System of Systems in Collaboration, Integration, and Logistics: A Value-Chain Based Paradigm of Supply Chain Management

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Abstract: The importance and complexity of the problems associated with coordinating multiple organizations to configure value propositions for customers has drawn the attention of multiple disciplines. In an effort to clarify and consolidate terms, this conceptual research examines both supply chain management (SCM) and system of systems (SoS) literature to postulate, from a value-chain perspective, what roles integration and collaboration play in helping supply chains satisfy customer requirements. A literature review analysis was used to identify the commonalities and differences between supply chain management and system of systems approaches to examining interfirm coordination of value creation efforts. Although a framework of integration and collaboration roles in value creation is proposed, further empirical testing of the concept is required to substantiate initial conclusions. The concepts proposed may help clarify where strategic and operational managers need to focus their efforts in coordinating supply chain member firms. The incorporation of SoS engineering into the supply chain field will draw the linkage between the constituent principles, and concepts of Systems Theory as appropriate for the supply chain management field. This is the first effort to reconcile two separate but parallel scholarship streams examining the coordination of multiple organizations in value creation. This research shows that there are some methodologies, principles, and methods from the SoS field that can supplement supply chain management research. Mainly due to a unit of analysis issue, systems based approaches have not been in the mainstream of supply chain management field development.

Keywords: supply chain management; systems of systems; value chain; integration

1. Introduction

Coordinating the processes between firms that enable the flow of goods and information from suppliers to consumers in an efficient and effective manner has never been easy. There are numerous examples where such business-to-business (B2B) process systems have failed, often due to the complexity of coordinating the aggregate systems, often resulting in catastrophic outcomes.

There are two high level types of failures in complex systems, namely manmade failures and natural failures. The former is attributed directly to human actions and behavior including physiological and psychological factors [1,2]. The latter is attributed directly to natural circumstances, including earthquakes, hurricanes and other natural disasters. This paper will focus on manmade failures in relationship to supply chains that are conceived, designed, and executed as manmade systems.

Prominent examples of human failures in managing B2B processes include Boeing's well-documented issues developing the 787 Dreamliner. Failures in building visibility in the supply chain, alignment of resource allocations, and relational understandings between Boeing and its suppliers, imposed billions of dollars of additional cost on the development. Boeing is not the only example of problems that develop from issues in coordinating supply chains that often result from manmade failures.

Naturally, given a problem of such importance and scope, a variety of disciplines have turned their attention to research of the matter. However, individual disciplines often develop unique paradigms to describe common phenomena [3]. Supply Chain Management (SCM) scholars have devoted an extensive literature to examine how extended enterprises cope with the complexity inherent in multiform cooperative efforts. Perhaps the most comprehensive and durable definition of SCM comes from Mentzer and his colleagues: "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company, and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" ([4], p. 18). This approach clearly subsumed concepts such as logistics, recognizing as it did that logistics' reach could not encompass disciplines such as customer relationship management, and procurement [5].

A key concern of scholars over the years has been the coordination mentioned by Mentzer and his colleagues [4] in the effort to avoid optimizing each function and operation of a given supply chain in isolation at the expense of overall supply chain performance. This is particularly the case as assumptions of mutual exclusivity and independence of system elements have limited applicability for complex systems. This is a problem amplified by limited units of analysis that, at best, tend to be confined to individual dyads, or even single firms [6]. Literature rarely offers cases that extend beyond single linkages, in spite of a noted need for demand and supply integration [7]. Such limited approaches are successful in systems that have a relatively static environment, clear boundaries, and direct relationships between entities [8,9]; however, such a limited approach is not successful when applied to complex (supply chain) systems that operate in turbulent environments. While the direct relationship between collaboration and performance is beyond the scope of this paper, based on the literature presented, there appears to be support for this relationship.

The continuing trend of using a network of business relationships [10] and the interdependence of B2B structures, suggests the need for a supplement level of thinking commensurate with the new realities. This supplement level of thinking can provide an opportunity to more critically examine and identify the potential contributions to B2B process failures (discussed later) from a different point of view. The failures and difficulties hint at the need for a different paradigm that might offer a change to the way of understanding and managing B2B process systems in an increasingly complex world.

In fact, the management of B2B process systems as a complex, uncertain, and emergent network of multiple interrelated supply chains can benefit from the inclusion of a view developed in systems engineering literature to describe B2B process interactions: the System of Systems (SoS) paradigm. SoS and related approaches are based in *holistic* thinking regarding the design, analysis, and transformation of multiple integrated complex systems as illustrated in Figure 1. Designing a supply chain from a complex SoS perspective and approach offers considerable potential to better deal with the realities that supply chain managers must grapple.

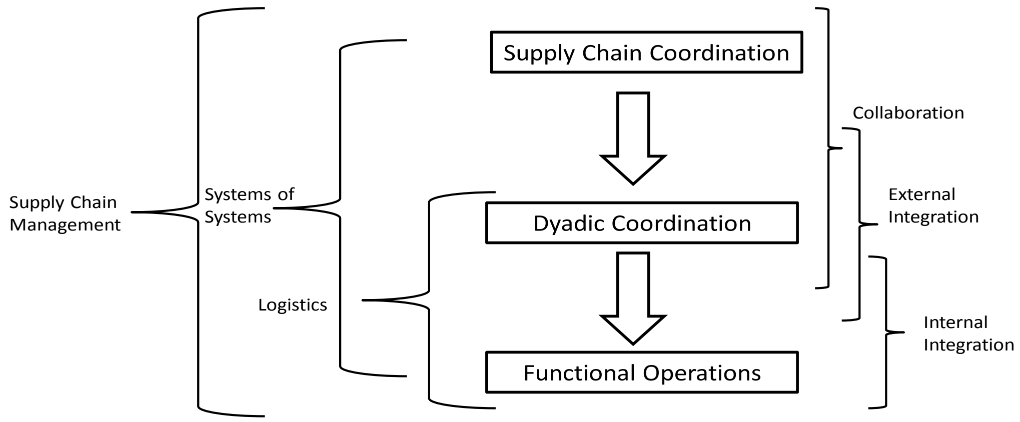

Figure 1. A conceptual hierarchy of supply chain management domains.

To explain this SoS paradigm in light of supply chain management, this conceptual study will:

1. Introduce the SoS as it relates to B2B process systems. It is argued that introducing SoS to the SCM field provides a supplement to the current SCM literature for better design, analysis and management of supply chains as complex SoS. While individual theories already in existence could explain aspects of supply chain phenomena, a SoS view could expand the lens used to examine B2B relationship processes. As coordinating activities lies at the heart of both SCM and SoS formulations, this paper will focus on collaboration and integration theories/concepts and discuss the influence and hierarchy of SoS into SCM, and thus enhance the current state of knowledge.
2. Discuss the main attributes of complex systems from a SoS perspective. These attributes are characteristic of supply chain management and therefore create conditions that can cause failures and potential disastrous consequences for the system. There is some convergence regarding the attributes of SoS and SCM existing principles and concepts in the conventional supply chain management literature. However, there is still a list of SoS principles, and concepts that can be applied in SCM field.
3. Detail the holistic systems based approach—that considers the spectrum of technology, organizational, managerial, human, social, policy, and political dimensions of the system domain—as well as illustrate how this approach parallels and supplements broader views of SCM. These elements of both SCM and SoS are particularly important as they capture the non-technical, relational factors contributing to B2B process failures. Thus, this conceptual research introduces the concept of SoS to the supply chain management domain to achieve four primary objectives:

    1. Consistent with the holistic paradigm that exists in SCM, the introduction of SoS—Systems theory, principles and concepts, can provide SCM scholars sources to stimulate more holistic decision making based on understating supply chains on a global level (holism).
    2. Identify cases where SCM and SoS have obscured commonalities and differences through jingle-jangle.
    3. Employ Porter's Value Chain to link the domain of SoS with SCM conceptualizations related to collaboration and integration.
    4. Establish an emerging SCM paradigm based on a holistic approach. This paper looks at collaboration and integration concepts from a new perspective, and a theory originating from systems engineering domain, that is SoS engineering.

The primary contribution of the SoS exploration in relationship to SCM is the introduction of a new and novel perspective for SCM. This SoS perspective does not diminish the current literature and perspective for SCM with respect to design, analysis, operation, or maintenance. On the contrary, SoS is examined as a potential complementary perspective and approach that might extend our understanding of the complex interrelationships between the constituent elements in a supply chain. SCM might benefit from inclusion of this different perspective. Similarly, SoS might also benefit through the examination of the filed considering the SCM literature and perspective. It is with this objective of expanding the conversation of SCM in fruitful ways that this paper is developed. The extensions offered by SoS are summarized in Table 1.

Table 1. SoS perspective contributions to SCM.

Attribute of Problem Domain	SoS Perspective	B2B Contribution
Quantifiable	Not easily	Consideration of complex system aspects of supply chains that are not easily quantifiable to support more holistic formulation of SCM considerations.
Structure	Emergent	Added emphasis on understanding and designing supply chains that are resilient across a broad spectrum of perturbations.
Analysis Approach	Holistic analysis	Extended consideration of the supply chain from a systemic (holistic) perspective that ranges across organizational, managerial, human, social, policy, and political dimensions.
Definition	Pluralism	Taking into account the variety of different, and potentially conflicting, perspectives concerning the supply chain as a system. Accounting for differences in interpretations of what constitutes the supply chain for purposes of systemic design, analysis, and development.
Environment	Turbulent	Appreciation of the complex turbulent nature of the environment within which the supply chain must operate.
Boundaries	Ambiguous	Understanding of the difficulties of establishing clear boundary conditions for a supply chain. This accounts for the dynamic, permeable, and continual shifting of boundaries for the supply chain.
Purpose	Consistent Reference Point	Supply chain continuity maintenance through the shared understanding of identity such that consistency in decisions, actions, and interpretations are supported by a common reference point.

Prior to the discussion of the role and hierarchy of SoS in a value-chain view of collaboration and integration in supply chains, we present in the next two sections the concept of SoS and the SoS attributes. After reviewing the literature in SoS and SCM fields, we found that there is some level of convergence with existing principles and concepts in both fields.

2. The Concept of System of Systems

At a most basic level, SoS is a collection of systems that has been designed, or integrated in the case of existing systems, to produce products, services, performance, or behavior beyond that which is achievable by the constituent systems. SoS is not 'new'. In fact, there are three main intervals that trace the history of SoS beginning with the recognition of complex systems (1950–1969) followed by the exploration of SoS (1970–1989), and concluding with the revolution of SoS (1990-present) [11].The SoS field has grown rapidly, especially during the last interval. Journals, books, symposiums, presentations, and centers related to SoS have flourished since the 1990s. Discussing the details of each interval is beyond the scope of this paper, however, Table 2 (following the previous work of [11]) summarizes the main theme for each interval along with some representative definitions of SoS introduced or used at the time.

Table 2. Representative perspectives of SoS across three intervals.

Interval	Main Theme	Definition of SoS
Recognition of Complex System (1920–1969)	The term 'holon', which becomes a major tenant in SoS, was introduced.	[12] used the term 'holon' to describe SoS which is the whole and the parts of a system.
The Exploration of SoS (1970–1989).	Focus on the whole to understand complex systems.	"A set of interrelated or integrated elements." ([13]). SoS is the integration of systems using a cybernetic perspective ([14], p.662). He used the term 'metasystem' to describe SoS.
The Revolution of SoS (1990–present)	Significant development of SoS field. Several perspectives, taxonomies, and methodologies have been proposed.	Large scale systems that should be considered as a whole to satisfy a specific mission [15].
		A network of interrelated systems working together to achieve a particular purpose. [16].
		The integration of multiple systems that is beyond the simple aggregation of individual systems [17].

While the list of definitions and perspectives is not complete, it demonstrates that the breadth of SoS and related thinking that has existed in multidisciplinary forms for a significant period of time. It is apparent from Table 2, along with SoS attributes that can be assigned from the literature, that most the perspectives and principles in SoS revolve around four main themes.

First, there is a generalized agreement that in SoS the focus should be on the whole rather than isolated elements (*holism*). Second, in SoS the focus expands beyond the purely technical aspects of the problem domain. This expansion includes the socio-technical aspects of the problem where organizational/managerial, human/social, and political/policy dimensions are critical in understanding and addressing issues in the problem domain [18–20]. Third, the SoS focus and perspective can serve to improve the design and management of a complex set of interrelated systems (e.g., a set of interrelated supply chain systems), where the performance of the whole is dependent not just on individual systems, but rather on the integrated set and their interactions. Fourth, the extrapolation of the SoS concept of the relationship among constituents in the larger system is instructive for SCM. For SoS, there is recognition that constituent systems have independence while also contributing to capabilities for a larger system (e.g., supply chain) that produces value beyond that which any individual system is capable. The next two sections articulate the main attributes of SoS across domains and explain how these attributes are applicable to the management of supply chains in complex systems.

3. Building a Context: SoS Attributes

The object of this section is to present the main SoS attributes, and to explore the level of convergence with existing principles and concepts for SCM. These attributes are based on extensive research, which was conducted to derive the most prevalent attributes characteristic of SoS [20,21]. Over a thousand different resources were reviewed, analyzed, and coded using inductive research reasoning and the Grounded Theory Coding approach as articulated by Strauss and Corbin [22]. From the coding analysis 6 main attributes emerged to construct SoS.

Describing the methodology used to derive these attributes is beyond the scope of this paper, but a description of each attribute that emerged from this research is provided. It is important to mention that the attributes are already embedded and discussed in the supply chain literature. However, there are many other SoS/Systems Theory principles that might be applicable to SCM. The idea is to show the convergence between SoS and SCM fields prior to discussing the complementary perspective and hierarchy of SoS in SCM.

3.1. Interconnectivity

SoS is composed of heterogeneous systems involving people, information, human/social and cultural identities, technology, hardware and software, and is also subject to multiple (potentially divergent) perspectives. To produce new behaviors, the heterogeneous systems need to interact, collaborate, and communicate within themselves as well as with one another. These heterogeneous systems must work together as a unity (integrated unit) to achieve the overall purpose of the SoS.

The notion of interconnectivity in SCM complements the notion of integration discussed below, by focusing on the heterogeneity of components and by highlighting that the behavior of the system as a whole. These behaviors, which exist as a product of interaction from multiple systems, is not to be explained solely by a reductionist understanding of the components but rather by looking at their patterns of interaction.

The components of the supply chain are indeed heterogeneous, first of all from a strategic perspective they have different sizes, corporate missions, and are supported by different equipment and IT systems. Still, with all this diversity, they still must find an optimal mechanism to synchronize their exchanges in order to be competitive as a supply chain, even though each member might be part of other supply chains.

3.2. Integration

With the increasing complexity of modern systems, many organizations tend to 'bring together' their internal or external systems to meet a goal and/or behavior that cannot be achieved by any of the individual systems acting independently. Integration includes (i) operational integration (ii) managerial integration and (iii) geographical integration. The integration of SoS dictates that the individual systems sacrifice some degree of autonomy to achieve the overall purpose [23]. A clear case free of jingle-jangle fallacies between SoS and SCM terminology surrounds the term integration. As noted, the SCM literature is replete with varied definitions of this term, perhaps the most seminal of which comes from Frohlich and Westbrook, who state that integration characterizes firms "that have carefully linked their internal processes to external suppliers and customers in unique supply chains" ([24], p. 185).

3.3. Evolutionary Development

Complex systems change over time because they interact with the surrounding environment and adjust to maintain a state of dynamic equilibrium. Thus, evolutionary development includes: (1) changes in technology; (2) evolving needs and requirements; (3) evolving social infrastructure; (4) a continuous life cycle; and (5) the redesign, redevelopment, and modification or improvement in the system's structure and behavior. This occurs in response to shifting conditions, either internally driven within the system or externally driven outside the system boundaries.

When observed through time, the supply chain's structure is dynamic. New nodes are added and old nodes are removed from the network as the supply chain continuously transforms to capture new markets, seeking cost reductions and quality of service improvements. This evolutionary development is an important property to consider. It means that very few circumstances offer the possibility of a green field development of a new supply chain. It is the adaptive development in a complex environment, which explains why the supply chain is structured is the way it is. Some nodes and structural subsets are highly entrenched whereas other nodes are more disposable. This evolutionary development characteristic of SoS closely resembles SCM concepts of adaptability. Like evolutionary development, adaptability research has examined how supply chains reconfigure combinations of vendors and suppliers in response to changing markets, conditions, and supply chains [25].

Like adaptability, the evolutionary view taken from the SoS perspective is helpful in guiding the strategic decision making processes which inevitably alter the structure of the supply chain. Decisions that will be influenced by the evolutionary development property include strategic sourcing, facility location, and channel segmentation decisions. Once some of these decisions are taken, they will constrain a number of other lower level decisions and become difficult to revise as they become more and more entrenched in the supply chain and will have many downstream implications. In the following section, emergence is examined. Emergence is related to evolutionary development in that emergence may occur at any point in the evolution of a complex system. Therefore, while emergence does potentially occur in the evolutionary unfolding of a system, the precise nature, timing, and impacts are not known in advance. Thus, emergence may signal short term evolutionary changes in a system.

3.4. Emergence

In SoS, emergence can be described as unpredicted behaviors/patterns resulting from the integration and the dynamic interaction between the constituent systems, their parts and the surrounding environment (open systems). These behaviors/patterns can be neither anticipated beforehand nor solely attributed to any of the constituent systems.

Supply chain literature has tended to visualize the issues described as emergence in SoS literature in terms of supply chain variability, or the "level of inconsistency, or volatility, in the flow of goods into, through, and out of a firm" ([26], p.557). While, like emergence, variability results from unpredictable sources, supply chain scholars have tended to view integration as the key to limiting variability's influence on performance. Thus, emergence in supply chains will inevitably occur and support evolutionary changes in response to the emergent conditions. The key is that evolution of the supply chain will depend on the response to emergent conditions. While the precise timing of emergent conditions is not known in advance, the continual adaptation of the supply chain provides for a longer term evolutionary trajectory in response to emergence.

3.5. Complexity

A SoS is comprised of multiple complex systems that are richly interconnected through communications and data flows. The individual systems are themselves complex. At a fundamental level, complexity suggests several central tenets. First, there exist a large number of entities/systems, which renders complete knowledge and performance predictability unattainable due to the sheer magnitude of the numbers of elements. Second, there is a high level of dynamic interrelationships among the individual entities/systems and their components. This gives rise to interconnections in a complex system, which rise exponentially with additional elements and are subject to shifts over time. Third, the involvement of multiple and potentially divergent stakeholders in complex systems introduces the existence of variability in stakeholders perceptions, motivations, and objectives. These variabilities can substantially influence complex system design, execution, and development. Fourth, complex system context includes the range of circumstances, factors, and conditions that exist beyond purely technical aspects. These contextual issues can introduce ambiguity and are subject to dramatic shifts over time. Traditional cause-effect relationships can be difficult for complex systems. Contextual issues include the range of policy, political, managerial, social and cultural, organizational, and financial aspects that impact system performance. In essence, complexity is a central aspect of systems and continues to escalate as a 'normal' condition of the landscape of 21st century systems.

Early efforts to define supply chain management have also grappled with the concept of complexity. Mentzer and his colleagues' [4] seminal work on the subject discussed three levels of supply chain complexity, comprising a hierarchy that includes direct, extended, and ultimate levels of complexity. The complexity issues explored in the SoS literature appear to correspond most closely to extended supply chain complexity, dealing as they do with coordinating information among multiple supplier and customer nodes within a supply chain, ranging from a given consumer back through a given raw material supplier. Further, the concept is related to SCM research in the field of transparency, and the effort to provide better visibility of supply and demand across the supply chain [6].

3.6. Ambiguity and High Level of Uncertainty

Not understanding a system's behavior and boundaries leads to potentially uncertain, unclear, or incomplete knowledge concerning a complex system. This state of knowledge calls to question the decision making process based on potentially limited, inaccurate, or inaccessible supporting information. Therefore, the capabilities to clearly define the boundaries of the system may be limited and further negatively impact decision processes. In SoS boundaries change over time based on one's evolving understanding and knowledge of the systems. This accounts for knowledge that more robustly supports decisions for complex systems.

SCM scholarship has long been concerned with both the ambiguity and uncertainty questions, exploring the area through research on visibility and transparency. Defining visibility as "the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit" (p. 1218). Barratt and Oke [27] postulated the links between visibility and firm performance.

In surveying the literature, we found these 6 main attributes that are not new to the supply chain management field [28]. However, there are many other SoS/Systems theory principles, and concepts that need to be introduced and addressed in the supply chain management field including *Minimum critical specification, the law of requisite variety, redundancy of potential command, darkness principle, eighty-twenty principle, homeostasis principle, basin of stability system principle, the system separability principle, the pareto principle, 'satisficing principle'* and others. Table 3 shows a sample of B2B failures relevant to SoS attributes and SCM attributes. The list is not exhaustive but it shows that the presence of all these attributes or a combination of them can obstruct the management of the supply chain and lead to failures in the B2B process system.

Table 3. SoS and SCM attributes relevant to B2B process issues.

Problem	Description of the Problem	Core Issue	Relevant SoS Attributes	Relevant SCM Attributes
General Motors (1980s–1990)	GM suffered from financial loss after buying more than 300 unnecessary and rarely used robots similar to those they already had. This bad investment cost GM millions of dollars with no profit.	Rapid technological changes and evolving need. Shifting and dynamic environment with multiple competitors and unpredictable contextual issues	Evolutionary Development, Complexity, Emergence	Adaptability, Complexity, Variability, Transparency
Toys R US.com (1999)	The online retailer accepted large orders to be delivered on Christmas Day as promised. Because the thousands of orders were above the system's capacity and resources, the company failed to deliver the orders on time and customers were irate	Mismatch of the system's capabilities with the system's resources. Unexpected large demand for the toys	Ambiguity and Uncertainty, Complexity, Emergence, Evolutionary Development	Ambiguity, Complexity, Adaptability, Variability, Transparency
Oil Industry (SCADA systems)	Attacks from hackers on SCADA systems can cause large-scale power outages and environmental disasters in addition to threatening the privacy of individuals. Based on Baker and Ivanov [29] report, the oil industry supply chain sector was reported to have the highest rate of distributed denial of service (DDoS) attacks, which have severe impacts on other systems and, therefore, cause harm to people.	Connections between the systems and their components in the oil industry are complex and ambiguous. The complex nature of the oil industry and the high level of interconnectivity create unexpected behavior such as the hackers attacks	Uncertainty, Complexity, Interconnectivity, Emergence, Ambiguity, Evolutionary Development, Integration	Ambiguity, Complexity, Integration, Adaptability, Variability, Transparency, Integration
Stuxnet Virus (2010)	In 2010 several Windows computers were attacked by the most serious cyber various in the world. This virus has a devastating impact on any supply chain in any sector.	Large number of hardware and software components, rich interactions, and unclear boundaries make it difficult to have a complete understanding of the system. This is a challenge to making appropriate decisions.	all the SoS attributes applied	Collaboration

Table 3. *Cont.*

Problem	Description of the Problem	Core Issue	Relevant SoS Attributes	Relevant SCM Attributes
Boeing Company (2010)	Using several suppliers from around the world to design the 787 Dreamliner aircraft caused Boeing to suffer a tremendous financial loss (billions of dollars), delays, and challenges to its supply chain system The causes of the problems can be traced to (1) a lack of visibility and management from the Boeing executives, (2) a mismatch between the allocation of resources such as work force, cost, time, expertise and the new system's requirements (787 aircraft) and, (3) a high level of contextual influence (e.g., different suppliers' worldviews)	The integration of multiple autonomous systems to design the new aircraft. Integration always produces new behaviors in the system, which in this example was considered a main reason for failure of the system. Lack of communication between the systems and their subsystems is another contributor to the failure	Integration, Emergence, Interconnectivity, Complexity	Integration, Adaptability, Integration, Complexity
Apple Power Book Laptops (1995–1997)	With the huge demand for its Mac laptops, Apple failed to fill and deliver all the orders and therefore lost approximately 1 billion dollars. The main reason for that loss was the inflexibility of Apple's supply chain system.	Dynamic and shifting demand. Insufficient resources to handle the demand because of the lack of knowledge in understanding the system's behavior and structure	Evolutionary Development, Complexity, Ambiguity and Uncertainty	Variability, Transparency, Complexity, Ambiguity

Developing terminology in the study of complex systems has been subject to jingle-jangle. Jingle fallacies are assumptions that two separate phenomena are the same because they have been given the same name, while jangle fallacies assume a single phenomenon is multiple differing phenomena because it has been given multiple differing names [30]. As SoS and SCM have been attempts to examine similar phenomena by different disciplines, introducing SoS perspectives into SCM requires examining where terminology entails such jingle-jangle.

The B2B process failures cited in this table demonstrate the utility of systems-based concepts to help understand the 'systemic' nature of the failures. To address and preclude such failures SoS can provide complementary methodologies, methods, and principles that can be embedded with the current methods and tools in SCM. For instance, across the examples, SoS is helpful in four primary ways:

1. *Explicit articulation of the system (of systems)*—this would have identified directly the issues related to capacity, interrelationships, boundaries, and resources.
2. *Environmental scanning and knowledge processing*—this would provide a 'systemic' design for early identification, assessment, and response to environmental perturbations. The result would be increased time for mounting more effective responses to supply chain issues stemming from environmental shifts.
3. *Integration of multiple systems*—this would have provided an emphasis and focus on purposeful integration of multiple, potentially disparate, systems to perform as a unity (integrated supply chain).
4. *Tension between integration and autonomy*—Balance must be achieved between the desires for autonomy by member systems with the integration necessary for performance of the larger system.

As coordinating activities lies at the heart of both SCM and SoS concepts, it is appropriate to begin by discussing the concepts of collaboration and integration and then, discuss the value-chain view of collaboration and integration in supply chain and the complementary perspective of SoS to SCM.

4. Collaboration and Integration Theories as the Coordinating Features of Supply Chains

Supply chain scholars have examined how combinations of firms jointly coordinate efforts, and resources to compete more efficiently and effectively for decades. The SCM discipline evolved from logistics [5], which itself emerged from a body of older disciplines, in part, as a means of identifying the distinctive value that firms harvest by addressing the place utility components of the marketing mix [31,32]. The most common concepts which SCM scholars have employed to describe how firms coordinate their efforts are *collaboration, and integration*.

Concepts of collaboration have varied over the years. Definitions have included trust, and commitment [33], informal processes relying on mutual respect, information sharing, and joint ownership of decisions and rewards [34], forecasting sharing [35] and working across boundaries to build value-adding offerings [36]. Collaboration has been characterized to occur between the functions within firms [37], as well as across boundaries between firms in a supply chain [36]. Table 4 contains a summary of key definitions of collaboration in supply chain literature. The general thread running through these definitions is that collaboration represents a culture of information-, planning-, risk-, and reward-sharing, among firms with similar attitudes towards the nature of the relationship that they share, and their unified efforts toward designing and adapting processes through which the participating firms may all prosper by more efficiently and effectively serving customers.

Table 4. Selected definitions of supply chain collaboration.

Author	Definition Quote	Page
Spekman et al. [33]	Collaboration requires high levels of trust, commitment and information sharing among supply chain partners. In addition, partners also share a common vision of the future.	57
Ellinger, [34]	Collaborative interdepartmental integration involves predominantly informal processes based on trust, mutual respect and information sharing, the joint ownership of decisions, and collective responsibility for outcomes.	86
Sheffi [38]	Collaboration among enterprises is what integrates the supply chain.	9
Stank et al. [39]	Collaboration is a process of decision making among interdependent parties. It involves joint ownership of decisions and collective responsibility for outcomes.	31
Shore and Venkatachalam [40]	Collaboration is defined here as the supplier's ability to work in a close partnership with headquarters and its willingness to share a range of data from cost structures to scheduling and logistics. It manifests itself in attitudes that relate to a supplier's integrity, trustworthiness, helpfulness in reducing costs, synergy with headquarters, and support of customer service.	809
Barratt [35]	... relationship based on information exchange in support of joint strategic, tactical and operational planning, forecasting and demand fulfillment processes.	74
Simatupang and Sridharan [41]	Supply chain collaboration is often defined as two or more chain members working together to create a competitive advantage through sharing information, making joint decisions, and sharing benefits which result from greater profitability of satisfying end customer needs than acting alone. Collaborative capability is the key ingredient in reaching external integration and cross-enterprise collaboration.	45, 46
Ellinger et al. [37]	Inter-functional collaboration is an informal, integrative work-management approach that involves departments working together, having a mutual understanding, sharing a common vision, sharing resources, and achieving goals collectively.	3
Stefansson [42]	Collaboration is a process of decision-making among interdependent parties.	81
Fawcett et al. [36]	SC Collaboration is defined here as the ability to work across organizational boundaries to build and manage unique value-added processes to better meet customer needs. [Supply chain] collaboration involves the sharing of resources-information, people, and technology-among [supply chain] members to create synergies for competitive advantage. Collaboration goes beyond managing transactions for efficiency to managing relationships for creativity and continuous improvement.	93
Min et al. [43]	Collaboration refers to a business process in which supply chain partners work together to achieve common goals that benefit them mutually.	294

Like collaboration, scholars have varied in their conceptualizations of integration. As illustrated in Table 5, definitions have included seamlessly linking processes between firms [44], collaborating at both the strategic and operational levels [45] to achieve efficient and effective services for customers [46], interconnecting business processes both within and between firms [47], cooperatively working to achieve mutual benefit, optimally managing flows of products, services, information, money, and decisions [48], and incorporating suppliers and their customers into cohesive networks [49]. Also like collaboration, integration is often characterized as having both internal and external forms [50]. However, the external components of integration have been segmented into unique dimensions based on whether the integration is with customers or suppliers [51]. As illustrated by Table 5, common threads running through the definitions are the linking of processes between and within firms, on both the strategic and operational levels, including information-, planning-, inventory-, and forecasts-sharing, in an effort to eliminate waste and duplication of effort while better and more profitably serving a customer.

Table 5. Selected Definitions of Supply Chain Integration.

Author	Definition Quote	Page
Kannan and Tan [52]	Supply chain integration (SCI) can be broadly defined as the extent to which supply chain members work cooperatively together to achieve mutually beneficial outcomes.	207
Chen et al. [53]	While SCM encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities, supply chain integration refers to linking major business functions and business processes within and across companies into a cohesive and high-performing business model.	27
Jayaram and Tan [47]	Supply chain integration refers to coordination mechanisms in the form of business processes that should be streamlined and interconnected both within and outside company boundaries.	262
Richey et al. [54]	... integration is defined as a firm's objective to attain operational and strategic efficiencies through collaboration among internal functions and with other firms.	238
Wolf [55]	The concept of supply chain integration asserts that the objectives of different functional areas and partners in a supply chain need to be arranged according to the same set of objectives in order to deliver the highest value to the customer. Poorly managed supply chains are characterized by one or more value creating processes working at cross purposes to other processes.	222
Wong et al. [51]	SCI [supply chain integration] is defined as the strategic collaboration of both intra-organizational and inter-organizational processes. We have collapsed SCI construct into three dimensions: customer, supplier and internal integration, to reflect its multidimensionality.	605
Huo [48]	SCI can be defined as the degree to which a firm can strategically collaborate with its SC partners and cooperatively manage intra- and inter-organisational processes to achieve effective and efficient flows of products, services, information, money, and decisions to provide the maximum value to the final customer with low costs and high speed.	596
Zhang and Huo [56]	SCI includes both economic actions, such as system alignment, information sharing, joint investments, and on-going inter-organizational social relationships among exchange partners.	545
Huang et al. [49]	SCI is a process of interaction and collaboration across firms that incorporate customers and suppliers into a cohesive supply network. A highly integrated supply chain can be a purposive integrated organisational entity that shapes the attraction, the selection, and the retention of the members of the collective; this type of supply chain can be referred to as a meta-organisation.	65
Mackelprang et al. [45]	A key aspect of strategic integration described in the literature is that it can confer both operational and strategic benefits, while operational integration can only confer operational benefits.	72

The definitions of collaboration and integration share much in common and thus, the academy has not settled upon a definitive demarcation between the two concepts. However, on carefully examining the literature referenced in Tables 4 and 5, both the definitions and measures of collaboration seem weighted towards establishing mutual goals and clarifying responsibilities between parties, while the definitions and measures of integration seem more weighted towards coordination and conduct of operations processes. Moreover, multiple definitions of integration suggest that it is a lower order construct of collaboration, or stems from collaboration ([46,48,51,54,57]). Furthermore, empirical research has suggested that the two constructs bear conceptual distinctions, and require further examination to better understand their differences [58]. Such distinctions have significant implications when the two constructs are considered as components of firms' individual and collective value chains.

5. A Value-Chain View of Collaboration and Integration in Supply Chains

Porter's Value-Chain concept (see Figure 2) is a view of how firms organize themselves to transfer and transform inputs in a way that infuses value-added utilities for customers [59]. Generally put, those activities of a firm most closely associated with adding utilities that the customer will find valuable are the primary activities of the value chain: inbound logistics, operations, outbound logistics, marketing and sales, and service. Alternatively, all remaining activities of a firm, which mainly serve to enable primary activities, are classified as secondary activities: firm infrastructure, human resource management, technology development, and procurement [60]. A variety of supply chain and logistic activities have been associated with components of the value chain, including IT connections [61,62], customer cost-versus-value estimates [63], and SCM strategies [64], among others.

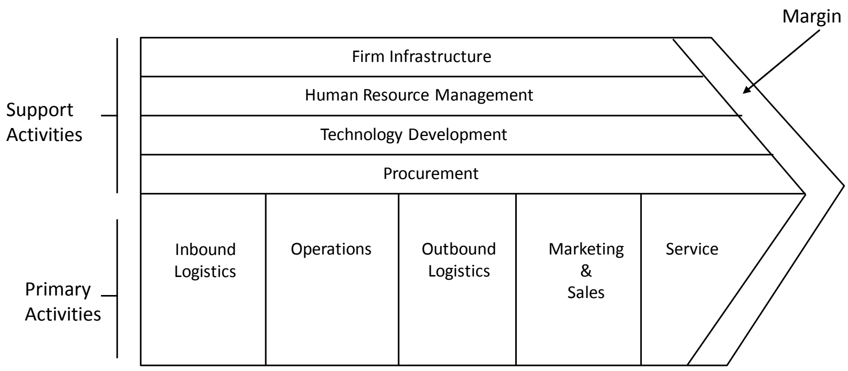

Figure 2. Porter's value chain.

A Value-Chain conceptualization in this case offers a means of delineating the firm activities most strongly related to collaboration and those most strongly related to integration. As noted, Tables 4 and 5 outline the differences between collaboration and integration, which are distinguished by defining relationship, and coordinating tasks, with collaboration representing a higher level of construct ([46,48,51,54,57]). Similarly, the activities classified by the Value-Chain model are also distinguished by broader, higher-level Secondary activities and more execution-oriented Primary activities.

The definition of primary activities offered in the Value-Chain conceptualization [59] would seem to most closely correspond to definitions of integration synthesized here. Those definitions lean towards the linking of operational processes. Alternatively, the definitions of collaboration synthesized here, weighted towards concepts of establishing goals, and clarifying responsibilities between supply chain members, would seem more closely associated with supporting activities of the Value-Chain, such as firm infrastructure. Thus, as illustrated in Figure 3, we suggest that collaboration is a means by which supply chains link the secondary activities of their constituents, while as illustrated in Figure 4, we view integration as the means by which supply chains link the primary activities of their members.

At first glance, the model we propose implies that supply chains are uncoordinated combinations of dyadic relationships. Definitions of collaboration [65] and integration [53] suggest that these constructs are not constrained within specific dyads. Systems engineering offers a concept of how organizations coordinate activities that might help illuminate how supply chains are holistically coordinated: SoS.

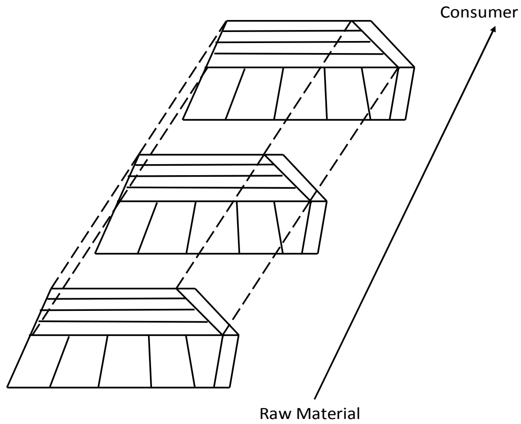

Figure 3. A value-chain view of supply chain collaboration.

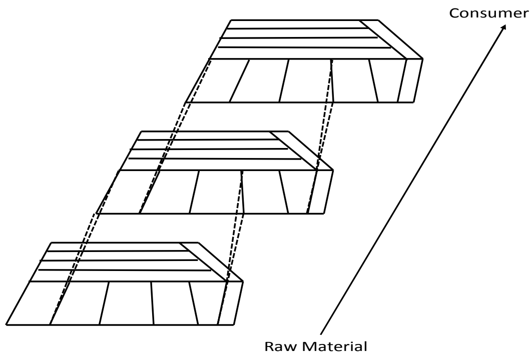

Figure 4. A value-chain view of supply chain external integration.

6. The Complementary Perspective of SoS in SCM

SoS engineering has been described in multiple different ways, including "The design, deployment, operation, and transformation of metasystems that must function as an integrated complex system to produce desirable results."([18], p.40). The SoS perspective emphasizes the integration of multiple heterogeneous systems into a coherent whole. This coherent whole has capabilities (performance, behavior) that exist beyond those of any of the constituent systems, and cannot be deduced (by reduction based analyses) or attributed to any of the singular member systems. From this perspective, it is a rather easy classification of SoS' role in supply chain management. What is equally important to supply chain management is the particular domain to which SoS engineering has been projected for application.

The question then becomes, where, exactly in the conceptualization of SCM, does the complementary perspective of SoS appear? SoS is inherently a multi-organizational concept, centered as it is on holistic solutions for problems between firms jointly reconfiguring inputs into market offerings ([18,23,66,67]). In our value chain perspective synthesis of integration, we suggest that external integration links the primary activities of firms, by linking processes [53] at both the strategic and operational levels [45], including informational, financial, and material flows [48] in order to more efficiently and effectively serve customers [46]. From a SoS perspective, integration functions at both internal and external levels. Thus, from the internal perspective, integration is essential to ensure that the constituent elements comprising the SoS are in fact linked such that the whole functions as a unity. In addition, integration is related to collaboration such that integration might be thought of as a byproduct of collaboration processes. Similarly, from the external perspective of integration for SoS, the different elements external to the SoS (in the environment) must be 'integrated' through collaboration processes. Thus, integration is achieved, both internally and externally, through collaboration processes serving to help the SoS sustainment performance. We also synthesize the literature to suggest that collaboration is an integration linkage between the secondary activities of value chains within a supply chain. This follows from collaboration's definitions as development of common offerings by multiple firms through cooperative approaches [36], based on trust and commitment [33], calling for joint decision making and responsibility sharing [34], and forecast building [35].

SoS's concepts of multiple systems designed to jointly produce offerings by creating compatibility between processes ([23,67–69]) parallels that of integration's definitions as the linking of processes ([48,53]). At the same time, SoS's concepts of incorporating the human/social and political policy dimensions of coordination into its domain ([15,23,70,71]) also parallel collaboration's focus on creating trust and commitment based [33] environments of mutually respectful joint-decision making environments [34]. Thus, as illustrated in Figure 5, we propose that the joint effect of secondary value chain activities, aligned by collaboration, shapes SoS effects, which in turn influence the integration of primary value chain activities.

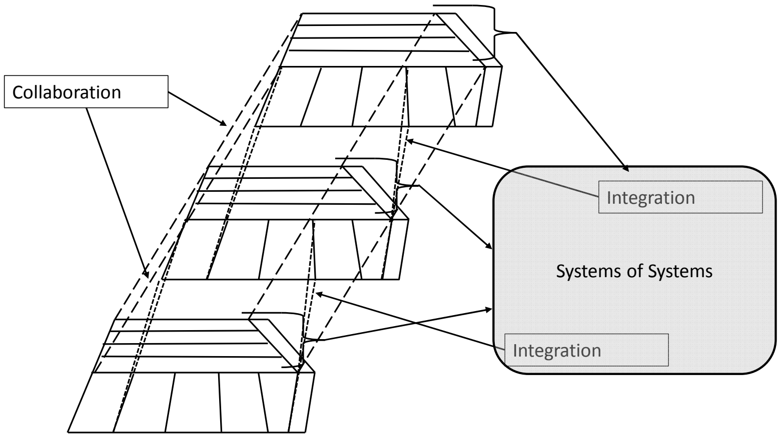

Figure 5. The roles of collaboration, integration, and systems of systems in linking value chains.

If there is a hierarchical distinction to be made, however, it lies in two factors. First, SoS is inherently a process-centric view of supply chain relationships, much like integration. Second, the synthesis of collaboration and integration presented here indicates that definitions of integration and collaboration lend themselves to the idea that collaboration is a higher order construct that shapes integration ([36,38,41]).

Care must be taken concerning attributions made with respect to a SoS perspective of integration projected to supply chain relationships. SoS integration has both an internal and external function. Internally, within the boundaries of the SoS, integration is focused on providing for interrelationships such that member systems 'join' an entity that exist beyond the individual member systems. Externally, integration suggests that the SoS must provide sufficient coupling with the elements outside the boundaries of the SoS such that it is sufficiently linked in relationship to external elements. Therefore, from the SoS perspective of integration (including both internal and external) there are implications for the function of supply chain relationships. This is particularly important from the viewpoint of integration being a direct byproduct of the design and execution of supply chain collaboration processes. In sum, supply chain collaboration processes are essential to produce both internal as well as external integration. This integration promotes consistency across the supply chain, or in SoS terms dampens oscillations stemming from disturbances in the normal function of the supply chain. Given the view that integration is a necessary, albeit insufficient, condition for collaboration effectiveness in the supply chain. This relationship is critical, particularly in consideration of design and analysis of supply chain connectedness. The SoS perspective of the link between collaboration and integration suggests that collaborative process in supply chains should be designed and executed with the necessary emphasis on integration as the byproduct of those collaboration processes. The degree to which supply chain collaboration processes are effective in producing integration will support a corresponding degree of supply chain performance sustainment.

Supply chain management has been characterized as "logistics taken across inter-organizational boundaries" in a manner that "include[s] more functions than logistics" ([5], p. 1). As illustrated in Figure 1, this suggests a structure that builds from logistics, through SoS, to SCM, as the domains concerned with collaboration and integration.

What we have proposed, joint effect of secondary value chain activities, aligned by collaboration, shapes SoS effects, which intern influence the integration of primary value chain activities, may prove insightful to the further maturation of the developing supply chain management field. The incorporation of SoS engineering and thinking into the B2B process systems offers several important contributions. First, SoS engineering has been built on the solid theoretical underpinning of Systems Theory ([72–74]). Therefore, the theoretical/conceptual basis for SoS engineering can provide a complementary perspective for B2B processes. The incorporation of SoS engineering into the B2B process systems will draw the underlying linkage between the constituent principles, and concepts of Systems Theory as appropriate for supply chain management field. Some exemplary principles include dynamic equilibrium, the law of requisite variety, subomtimization principle, darkness principle, eighty-twenty principle, homeostasis principle, basin of stability system principle, the system separability principle, the omnivory principle, and 'satisficing principle' ([67,74–79]). This sample list of SoS/Systems Theory principles needs to be introduced and addressed in supply chain management field to enhance the current state of knowledge. Table 6 present a sample of guiding SoS principles along with short description.

Table 6. System-of-Systems guiding principles.

Systems Principle	Theme
Metasystem [80]	Provides the structure of relationships that integrate a system. Relieve the tensions between the autonomy of the subsystems and the integration of the higher level system.
Value Free Production	A system accords no value judgments to output or outcomes that it produces. There are no bad systems, just systems that disappoint the interpretation of the products they generate.
Equifinality [73]	There are multiple paths, from different initial conditions, that can result in the same output/outcomes for a complex system.
Minimum Critical Specification [81]	Determine the essential constrains to achieve the performance level required by a system. Over specification unnecessarily limits the flexibility in the operation of the system to respond to varying conditions.
Iteration [82]	The design and transformation of complex systems are interpretative process that continue to evolve with additional information and understanding of the system and context.
Self-organization [83]	The majority of the structural and behavioral patterns for a complex system only emerge after operation of the system in its environment (context). Unintended consequences can be mitigated through design for robust feedback, feedforward, and redundancy of critical system functions.
Basin of Stability [83]	A system will seek a level of stability (lowest energy state) unless acted on by external forces. The system will move to a new basin of stability (past a threshold) only when sufficient energy (resources) are applied to provide 'momentum' necessary to shift to the new basin of stability
System Control [14]	System control is best established as close as possible to the point at which decisive decision and action can be taken in response to variances to system performance. This encourages maximum autonomy (freedom and independence of decision, action, and interpretation) for system constituents in the best position to make timely decisions that can reduce variances at the point that they occur.
Satisficing Solutions [84]	Solutions to complex system problems should be focused not on achieving 'optimal' results (pursuit of a solution that exist above all others, regardless of other considerations, e.g., resources). Instead, pursuit of 'satisficing' (good enough) results.
Omnivory principle [85]	Stability in a complex system is achieved by having a greater number of different pathways for their flow to the main system components (i.e., modification of internal structures to enable intake of different resources. In other words, 'don't put all your eggs in one basket.')

Second, there are particular methodologies and methods from the systems field that can extend the reach of supply chain management. These systems based approaches have not been in the mainstream of supply chain management field development. However, they might bring some insights that can serve to amplify the field and extend the capabilities for practitioners to be more effective in dealing with the complexities experienced in supply chains. Some of these system-based approaches are Soft System Methodology, Viable System Model and Gibson's System Analysis Methodology ([73,82,86,87]). *Third*, the particular worldview upon which SoS engineering is built is based in appreciation of the *holistic* paradigm that underpins Systems Theory. This suggests consideration of the totality of technical, human, social, organizational, managerial, policy, and political dimensions of supply chain management. This more expansive thinking, coupled with the methods to exploit the thinking, might challenge the supply chain management field to open up to new possibilities.

Table 7 shows some of the SoS methodologies/methods that can be extended to reach the supply chain management community. These introduced methodologies provide SCM practitioners with a supplement toolset, in addition to the current tools in SCM, to be more effective in engaging complexities emerged in supply chains.

Table 7. Systems-based Methodologies, Themes, and Utility for SCM.

System Method(ology)	Major Theme	Potential Utility in SCM
Viable System Model, Beer [14]	Diagnosis of structural system functions, relationships, and communications channels necessary for any system to maintain existence.	An approach that can identify system structural deficiencies in the supply chain. Traces deficiency to performance of system functions and communication channels from a management cybernetics perspective.
Sociotechnical Systems, Taylor and Felten [81]	Work system analysis and redesign based on joint optimization of the social and technical subsystems for performing work.	Provides for examination of technical aspects of SCM issues and deficiencies of the social components of the SCM. Can establish a more comprehensive set of considerations for SCM development, including social as well as technical concerns.
Systems Engineering, Sage [88]	Structured formulation, analysis and interpretation of the technical, human, and organizational aspects of complex systems to address needs or resolve problems subject to cost, schedule, and operational performance constraints.	Treatment of supply chain problems from a systems perspective that seeks to understand SCM issues related to deficiencies across cost, schedule, and technical performance requirements.
System Dynamics, Maani and Cavana, [89]	Computer modeling and simulation approach to understand the relationships and underlying behavior of complex systems.	Can be influential in understanding the nature of relationships in the SC, particularly impacts across hard and soft variables that can influence system performance over time. Can examine potential SCM modifications for impacts prior to deployment.
Soft Systems Methodology, Checkland [87]	A process of inquiry focused on formulation of ill-structured problems appreciative of multiple perspectives.	Provides for a more comprehensive structuring of SCM problems rooted in the underlying system. Can be effective in identification of technically and culturally feasible improvements for problematic SCM issues.
Total Systems Intervention, Flood and Jackson [90]	A system problem solving approach based on creative thinking, appropriate method selection, and implementation of method based change proposals to resolve complex issues.	Can contribute to formulation of the SCM problem domain, and suggest appropriate systems based approach(es) that are most appropriate to the situation/system under consideration.
Strategic Assumption Surfacing and Testing, Mason and Mitroff [91]	Focuses on the resolution of ill-structured problems by identifying multiple stakeholders, their assumptions, and engaging in dialectical debate over proposed strategies to develop a higher-level course of action.	For SCM problems that involve multiple stakeholders, with potentially divergent or conflicting perspectives, can provide an approach to articulate and examine the problem(s)/situation. Can offer alternative formulations in ways that alternative paths forward might be identified.
Gibson's Systems Analysis Methodology, Gibson, et al. [82]	Provides six iterative phases to study complex systems problems, including System Goals, Ranking Criteria, Alternative Development, Alternative Ranking, Iteration, and Action.	Offers SCM an approach to conduct rigorous systems-based generalization of the SC or problems and objective evaluation of different response alternatives.
Complex System Governance, Keating, et al. [92]	Design, execution, and development of nine metasystem functions responsible for achievement of control, communications, integration, and coordination that produces system performance such that viability [existence] is maintained.	Can provide for comprehensive identification and assessment of systems based pathologies (issues) that occur in the SC functions. Emphasis on implications for redesign, execution modification, and SC development can be achieved.

Based on what we have proposed and the clear overlap between SoS attributes and SCM principles and concepts (Figure 1), we suggest two primary contributions that SoS can make to the supply chain management literature:

I. SoS provides a sound theoretical basis for further development of supply chain management study. By supplementing supply chain management thought and practice with the underlying Systems Theory upon which SoS is based, a broader set of language, thinking, and corresponding methods can be introduced in SCM, perhaps more fully capturing and addressing the problem. Therefore, the exposure of supply chain management to a new and wider array of systems theory based concepts may prove insightful for consideration related to supply chain management. For example, concepts and principles such as holism, eighty-twenty principle, homeostasis principle, basin of stability system principle self-organization, requisite saliency, requisite parsimony, and emergence certainly offer an expansion of the language and corresponding conceptualization of supply chain management problems faced by practitioners (See Table 6). The systems based language and concepts may provide a different framing of familiar supply chain management issues for practitioners. The basis of this underlying systems language and practical utility can be found in the work of ([58,67,74–77,83,93,94]) and others. Therefore, with application of complementary systemic thinking/language alternative decisions, action, and interpretations can invoke different 'system-based' paths forward to previously intractable supply chain management problems.

II. SoS provides access to a host of systems-based approaches for dealing with modern complex systems and their problems. Such exposure to this wider array of possible systems-based approaches (e.g., viable system model, complex system governance, soft systems methodology) can add to the (systems-based) approaches available to practitioners of supply chain management. A primary entry point for SoS application to supply chain management can be found in the SoS engineering methodology [95]. This methodology provides a strong initial framing of the problem domain for a system of interest. This opens an entirely new set of methodologies and corresponding methods, tools, and techniques that can be embedded with current SCM tools, for supply chain management professionals. Based on the conceptual hierarchy of SCM Domains and SoS, we present some implications for supply chain management from a SoS perspective. (See Table 8).

Table 8. Implications for supply chain management.

Complex System Problem Domain	Description	Implications for Supply Chain Management	Paralleling Research or Research Calls in Supply Chain Management
Information Proliferation	Expansion of information intensive systems and technologies and exponential rise in information.	Criticality of robust design for information as a key artifact that is both consumed and produced throughout a supply chain.	Big Data [96]
Divergent Stakeholders	Multiple stakeholders with potentially incompatible worldviews and divergent objectives, often politically driven.	An assumption of unitary perspectives and objectives within the supply chain is naïve. Care must be taken to understand multiple, and potentially conflicting perspectives.	Sustainable Supply Chain Management [97]
Unstable Resources	Scarce and dynamically shifting resources that create a source of uncertainty and potential instabilities in operations.	Realities of the supply chain dictate that resources may be unstable and that sufficient redundancy should be built to preclude single points of resource failure.	Risk Management [98]
Emergence Domination	Constantly shifting conditions and emergent understanding of problems and context dominate the landscape. Assumptions of stable development of requirements and well understood life cycle driven approaches are unrealistic.	Future supply chains will not be capable of full understanding, explanation, or necessarily stable planning. Focus must be on robust designs that are built to respond to a wide range of unplanned emergent conditions and disruptions.	Agility [99] Adaptability [25]

Table 8. *Cont.*

Complex System Problem Domain	Description	Implications for Supply Chain Management	Paralleling Research or Research Calls in Supply Chain Management
Technology Integration	Technology advancements that outpace the capabilities, and potential compatibility, of infrastructures necessary to support their development, integration, maintenance, and evolution.	Technology is necessary, but not sufficient, to effectiveness in supply chain management. Technology must be considered in relation to the holistic spectrum of organizational, social, policy, and political implications.	Technological Readiness [100]. Technological Turbulence [101].
Demands for Responsive Action	Urgency in demands for responsive action and solution development to alleviate mission shortfalls.	Supply chain decisions, actions, and interpretations initiated out of urgency must take into account deeper and longer range potential impacts on the overall supply chain.	Flexibility [102]. Responsiveness [103].
Sacrifice of the Long View	Abdication of long term thinking in response to immediate perceived operational needs—rendering traditional forms of long range planning virtually innocuous	Balance must be achieved between urgent short term thinking and important long term thinking. Tension between these can help the supply chain to both perform near term and maintain fruitful trajectory.	Supply Chain Orientation [4]
Unstable Planning	Increasing complexities and uncertainties question the ability of traditional systematic planning approaches, based in assumptions of stability, to effectively plan for present and future operations.	Planning for supply chains must consider the level of stability for the planning horizon. Increased emphasis on planning designs that are sufficiently robust and reconfigurable to adjust to the rate of change in the supply change.	Adaptability [25]. Responsiveness [103].

7. Case Example

In an effort to show the complementary perspective of SoS in B2B processes, this section provides a discussion on Viable System Model VSM/SoS methodology and its implication in the B2B process. The intent is to provide a supplement with the current B2B literature (See Table 9).

VSM is a construct to understand issues related to complex system structure (i.e., lack of coordination in B2B processes) through six modified functions and eight communication channels. A set of 6 interrelated functions that act to maintain existence of a complex system and 8 communication channels that act, through their own mechanisms, to provide information flow within the system and relationships among system entities that provide a basis for making decisions, taking actions, and facilitating interpretation. VSM helps to minimize the tension between autonomy-integration, collaboration-integration, and stability-change. The eight communication channels are adapted from the work of Beer [1] and extensions of Keating et al. [18]:

Table 9. Case scenario.

6 SoS Functions	8 SoS Communications Channels and Responsibility	Implications to B2B Process (Collaboration and Integration)
Policy and Identity Function: Focuses on overall steering and trajectory for the system. Focuses on the specific context within which the system is embedded (set of factors, circumstances, conditions, or patterns that enable or constrain execution of the system).	Command and dialog Channels: • Provides non-negotiable direction based on 'system level' decisions. • Provides for examination of system decisions, actions, and interpretation for consistency with system performance and identity.	External Collaboration and Relational Governance: • Establish, maintain, identify and balance between current and future focus. • Ensure that previously agreed upon operations and monitoring procedures are followed.
Strategic System Monitoring Function: Focuses on oversight of the system performance indicators at a strategic level and identifies performance that exceeds or fails to meet established expectations.	Algedonic Channel: • Provides a 'bypass' of all channels when the integrity of the system is threatened • instant alert to crisis or potentially catastrophic situations for the system.	Modularity/Flexibility: • Plan for alternative means of redirecting or reconfiguring supply chain flows to respond to potential disruptions.

Table 9. *Cont.*

6 SoS Functions	8 SoS Communications Channels and Responsibility	Implications to B2B Process (Collaboration and Integration)
System development, learning and transformation Function: Maintains the models of the current and future system, concentrating on the long range development of the system to ensure future viability.	Learning Channel: • Provides detection and correction of error within the system as well as integrated systems. focused on system design issues as opposed to execution.	Market Orientation: • Interfunctional coordination dimension • Intelligence dissemination dimension.
Environmental Scanning Function: Designs, deploys, monitors, and communicates sensing of the environment for trends, patters, or events with implications for both present and future system viability.	Scanning Channel: • Provides design for sensing of the external environment. • Identifies environmental patterns, activities, or events with system implications.	Market Orientation: • Competitor and Customer Orientation dimensions • Intelligence gathering dimension.
Systems Operations and performance Function: Focuses on the day-to-day execution to ensure that the overall system maintains established performance level. Identifies and assesses aberrant conditions, exceeded thresholds or anomalies.	Resource bargain/integration Channel: • Determines and allocates the resources (manpower, material, money, information, support). • Defines performance levels, responsibilities, and accountability. Operation Channel: • Provides for the routine interface focused on near term operational focus. • Concentrated on direction for system production (products, attempts to examine similar phenomena , processes, information) consumed external to the system.	Internal Collaboration/ Integration and S&OP: • Ensures common priorities, and establishment of goals, responsibilities, and monitoring systems.
Information and communications Function: Designs, establishes, and maintains the flow of information and consistent interpretation of exchanges (communication channels) necessary to execute the SoS functions.	Informing Channel: • Provides for flow and access to routine information in the system or between the sub-systems. Coordination Channel: • Provides balance and stability among the SoS functions. Ensures that information concerning decisions and actions necessary to prevent disturbances are shared within the SoS functions.	Internal Collaboration/ Integration and S&OP: • Ensures common priorities, and establishment of goals, responsibilities, and monitoring systems.

Thus, the case example highlights that there are multiple parallels between SoS and SCM approaches. In particular, there are three primary conclusions we offer related to SoS and SCM parallels. First, a closer examination suggests that the identity function plays a major role in both SoS and B2B processes, particularly with respect to providing a balance between present and future focus. Second, the necessity for maintenance of a flexible/adaptive stance is critical in both SoS as well as SCM. This implies that the design must monitor, accommodate, and provide resilience to a variety of potential disturbances. Third, the identification of specific channels of communication and corresponding functions for SoS are consistent with the demands of SCM for detailed design, execution, and monitoring necessary to assure continued performance (viability). As the example above suggests, SCM scholars might be able to leverage SoS thinking and methods to more precisely address how interfirm complexities might be resolved.

8. Conclusions and Limitations

This research paper was driven by four primary points of emphasis: introducing the SoS perspective to the supply chain management field, providing the level of significant convergence for both domains, addressing jingle-jangle fallacies between SCM and SoS literatures, and showing how the holistic systems based approach might be used as a complementary approach to treat the supply chain in a manner more consistent with the complexities that are part of modern supply chains. Six main literature derived attributes describing SoS were presented as a foundation to establish the linkage and applicability of SoS to the SCM field. Literature strongly suggests that these attributes are also endemic to supply chains.

The six attributes include integration (operational and managerial integration), interconnectivity (heterogeneous systems consisting people, technology, software, and hardware), emergence (unintended behaviors/patterns resulting from the integration between the systems), *complexity* (dynamic environment and multiple divergent perspectives), *evolutionary development* (evolving needs and social infrastructure), and *ambiguity* (lack of understanding of system's structure and behavior. While these attributes are not presented as a 'complete set', they do suggest the appropriateness of SoS thinking to supply chains.

Managing B2B processes effectively under these attributes, or a combination of them, can be enhanced by incorporation of a 'system of systems' thinking paradigm. This paradigm suggests that a more *'holistic'* perspective of the supply chain, based on consideration of not only the technical perspective but also the social/human, managerial /organization and political/policy dimensions, might enhance practices in dealing more effectively with modern supply chains. Thus, this paper introduced SoS perspective, and corresponding paradigm, as applicable to the field of supply chain management. This perspective is built based on appreciation of the holistic paradigm that underpins Systems Theory in conjunction with the corresponding systems thinking principles. Ultimately, practitioners of supply chain management will have access to a wider (systems based) array of thinking, actionable methods, and the corresponding paradigm (worldview) upon which to continue maturation of the field.

As with any research, this study includes limitations, the principle one being that it is conceptual. SCM scholarship has a rich tradition of introducing or exploring ideas through conceptual research, including Collaborative Information Sharing and Incentive Alignment [41], the relative order of SCM, logistics, marketing, production and OM [98], and even the definition of SCM itself [4,5]. However, future research should include case studies to assess the relationships between constructs proposed here, and empirical studies to quantitatively establish the strength of such relationships.

In conclusion, we offer three important points that summarize our hope and challenges for incorporation of SoS into the development of the SCM field:

1. *Increasing complexity of supply chains demands new thinking, methods, and tools*—approaches to supply chains based in reductionist analysis are not likely to have the success they have had in the past. Reductionist analysis proceeds from the assumption that the understanding of a system is not lost from the successive breaking of the system to smaller constituent elements. For supply chains an example would be to assume that a complex supply chain can 'reduced' to the point that optimization techniques could be applied. While this assumption may be appropriate for some supply chains, for truly complex supply chains is may be incapable of addressing complexities in supply chains dominated by irreducible factors (e.g., power, politics, divisive relationships) that cannot be analyzed our understood (i.e., reduced) by traditional means (e.g., supply chain optimization). The new environment for supply chains is dominated by conditions of emergence, uncertainty, and ambiguity. These conditions are no longer the exception, but are now the dominant characterization of modern supply chains.
2. *System of systems 'holistic' systems theoretic based paradigm offers SCM a fruitful path forward to accelerate development*—incorporation of SoS and the underlying complex systems paradigm offers

the emerging SCM field a chance to accelerate development in new and novel ways. The inclusion of both 'hard' and 'soft' systems thinking are more indicative of the realities faced by practitioners in SCM. The SoS field brings a strong heritage of effectively including holistic appreciation of complexities that are the hallmarks of modern supply chains.

3. *Supply Chain Management can be enhanced for practitioners by inclusion of existing models, methodologies, and techniques from SoS and related systems based fields*—there is a rich theoretical, methodological, and practice basis that demark the SoS field and associated systems based approaches. Inclusion of these perspectives and approaches can amplify the effectiveness of practitioners that must contend with increasingly complex supply chains. This does not preclude the inclusion and appreciation of the prior knowledge generated and successfully applied to SCM. On the contrary, this inclusion only serves to extend SCM capabilities, thinking, and maturation of the field by incorporation of SoS.

SCM is a maturing field that has seen a marked level of success in dealing more effectively with supply chains and their corresponding problems. However, neither supply chains nor the SCM field is insulated from the increasing complexity, emergence, uncertainty, and ambiguity characteristic of modern enterprises and their associated supply chain problems. We propose extension of SCM effectiveness for practitioners by inclusion of the tenets of SoS field and the paradigm this field offers to enhance the prospects for future development of the SCM field.

Neither SCM nor SoS are the definitive or universally accepted approaches to dealing with the increasing complexities of modern complex systems, their associated supply chains, or the problems they generate. However, this exploration into the intersection of these separately developed fields has demonstrated that there is much to be gained by their joint development and application. Although this is a first foray into their potential for consideration a complementary approaches, we acknowledge that there is much more that can be done. However, for SCM practitioners who are experiencing complex problems, environments, and conditions such as we suggest in this paper, there are some immediate applications that might be pursued. We close by suggesting that practitioners and researchers wishing to continue this SoS extrapolation into the SCM field might start with several of the SoS articles referenced, including ([11,19,67,73,75,79,82,87,94]). It seems that there is much to be gained through the sharing and joint development of the SoS and SCM fields.

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