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LiSC Model: an innovative paradigm for Liquid Supply Chain

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Abstract

Supply chain is studied all over the world by a number of researchers who propose description models, analyze quantitatively its efficiency and, more recently, create its digital twins. In the last years, according to some unpredictable events which upset the global economy, supply chain showed the capacity to change itself according to the new constraints but, also, the new opportunities raised. Classical models developed to describe supply chain are not powerful enough to model what today I4.0 pillars allow if we use open innovation as an extraordinary amplifier. Thus, the supply chain changes shape and connections. In this perspective, the paper propose and describe a new construct of supply chain called: Liquid Supply Chain (LiSC). It takes into account also the extraordinary effects of pandemic diffusion of Covid-19 virus and its influence on the companies. A critical comparison with other existing models is proposed and discussed.

Keywords: supply chain, antifragility, reactivity, open innovation

1. Introduction

The competition is today played in the global arena, so the cost-efficiency analysis alone may be not enough to evaluate the performance of a supply chain (SC) model and its value in terms of long-term reliability. There are many definitions of SC, but for this paper the one that will be used derives from “The Global Supply Chain Forum”

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[1] and indicates the supply chain management as "*the integration of key business processes from end-user through original suppliers that provide products, services, and information able to add value for customers and other stakeholders*". The product-life-cycle is shorter than in the past, with a consequential high rate of uncertainty due to the volatility of demand, but also to the many external disruptions that may occur, as we all have clearly understood after the Covid-19 emergency. Due to the competitive environments which contribute to uncertainty, change is becoming the default status for many sectors, therefore an important challenge for organizations is to mitigate the risk by making supply chains more resilient and adaptive [2]. The Covid-19 pandemic, with the consequent lock-down measures enforced by Governments, had a considerable impact on the industrial world. In an ecosystem characterized by the occurrence of unexpected events, unstable relationships, and continuous change, companies have to be able to manage and promptly change their operating business, not only in order to survive but also to maintain a sustainable competitive advantage. These factors force also firms to redesign their SCs, in order to be more adaptive and ready to change quickly to better meet the customer needs or to stand to the market constraints. [3]. To fully understand the crucial role of SCs and the need for a solution to increase their adaptiveness, it is enough to consider what happened during the Covid-19 emergency. The demand for some products has massively increased (e.g. facial masks, latex gloves, hand sanitizer, disinfection devices and so on) while firms, hospitals, and even governments suffered the lack of reliable supplies [4]. On the other hand, a lot of companies had to face the opposite problem, with their markets which literally collapsed. Here, the problem of SC readiness to survive for future crises arose and the need to propose new SC model are required [4]. In this context, Digital Transformation (DT) is generating a deep change in business models and organizations [5] and SCs are experimenting with processes of extreme disintegration in an open innovation context where, knowledge and technologies of specific firms, can be mutually shared at convenience with others in several ways (resource sharing approach). By embedding technologies and knowledge, in fact, each piece can be integrated with other chains in several ways, from the perspective of value creation. This implies additional challenges in managing the increasing amount of knowledge and information flows. Consequently, as the world becomes increasingly interconnected, SCs grow in complexity, too. Stemming from the concepts highlighted above, this paper has the aim to implement a new SC model, that could be considered a maturity model, that operates in an open innovation-oriented environment, including new technologies and allowing firms to react effectively to endogenous or exogenous shocks. Thus, the present work attempts to answer the following research questions: *Which technologies and knowledge should be owned by a firm itself, and which should it buy on the market? Which is the level of integration should that firms develop between themselves and their suppliers?*

2. Digital Transformation (DT) and Supply Chain: literature review

The introduction of digital transformation into manufacturing has many impacts on the whole SC. Collaboration between suppliers, manufacturers and customers is crucial to increase the efficiency of all the process from when the order is dispatched until the end-of-life of the product. Furthermore, the introduction of digitalization and automation of processes pushes the whole SC structure to change. However, digitalization has also leads to disruptive changes that affect significantly SCs and will continue generating changes in the future. Considering that, it is crucial to understand the opportunities and the impact of DT on the SC configuration models as a whole and vice versa, especially under endogenous or exogenous shocks [6]. Information technology is fundamental for the improvement of the SC as it has the potential of integrating various suppliers, customers and processes, as well as it has the ability to enhance communication in terms of data collection and information sharing across the SC [7, 8]. The present session discuss the main SC model proposed by introducing and applying the DT. Some authors introduced the concept of Digital Supply Chain [5] by proposing "… *a digital community of partners executing coordinated processes in a more organized and informed way than in the past*" [9]. To achieve this ambitious goal, the aid of technology is necessary, and DT plays a crucial role. Consequently, across the different changes in the SC

models, a new issue is emerging and concerns both technology and knowledge sharing across the SCs. Sharing is commonly cited as the most valuable key for reducing SC connected costs [10]. Recently, the adoption of new electronic traceability systems by companies, for example, takes place to track inventory, sales, purchases as well as production for the best possible SC management. Digital SCs are reinforcing the concept of networks, since they use many different technologies to develop resilient systems in various stages of SCs, including new product development, manufacturing, procurement, planning, logistics and marketing. The increasing of connectivity, in fact, among SC stakeholders, as the growing the frequency and the intensity of their collaboration, implies the necessity to manage SC at a network level [11]. In early 2000s, the ideas of dynamic SC formations have found first developments in the area of virtual enterprises and collaborative networks [12, 13, 14; 15]. Some authors developed the concept of holistic SC networks that are composed of a group of intersecting SCs which are intertwined [26,36]. The SC intertwining can also be encountered in industrial symbiosis, as well as in circular and sharing economies [16]. An example is a symbiosis of commercial and humanitarian logistics when several business and humanitarian SCs are sharing the warehouse facilities [17, 18]. Considering the practical environments, some authors [20] point to "complex, dynamic, interconnected SC" highlighting to the role of information technology in synchronizing the SCs within the value webs. Some authors introduce for the first time the term 'Intertwined Supply Network' (ISN) that summarizes entireties of interconnected SCs which in their integrity secure the provision of society and markets with goods and services [4]. Thus, according to some authors, SCs rarely represent single, isolated networks but are rather open systems that are characterized by structural dynamics [19,20]. In contrast to linearly directed SCs or supply networks with static structures, the firms in the ISNs may exhibit multiple behaviours in buyer-supplier relations (i.e. behavioural dynamics) being buyers and suppliers in interconnected or even competing SCs simultaneously. Other relevant research streams can be found in the theories of complex adaptive systems [20] and SC structural dynamics [19]. Industry 4.0 and cyber-physical manufacturing have significantly transformed the SCs and increased their intertwining [21,22,23]. Some works showed different forms of SC interconnections in the sharing and circular economies [16]. Growing information sharing and synchronization of operations between SC partners help to decrease the total costs while increasing both the efficiency and the agility of SCs as a whole [24,25]. Improved transparency and collaboration along with the SC network also leads to increased trust and stronger relationships between the SCs operators. In this context, the necessity of a Smart SC is emerging [24], in order to generate more relevant information characterized by various elements, ranging from the correct type of information to improved quality, better timing and speed, the ease of access and suitable controllability in regard to privacy issues [26]. The combination of mobile, cloud and smart systems is a key enabler that can lead to the creation of new types of SCs where physical and digital flows are merged [27]. Then, based on that, companies can transform themselves into real-time firms where the physical and the information flow is integrated [28]. Through the real-time information exchange, enhancement of SC responsiveness can be achieved [29]. The result is a cost reduction due to the real-time optimization, as well as the rising the agility of the SC and the increasing speed of information flow, due to the real-time resource tracking [29]. Moreover, the collaboration between the parties involved within a SC needs to be integrally managed. Then, where existing collaboration platforms failed, a cloud-based platform for an improved process of data and information sharing between all stakeholders is a basic requirement for enhanced collaboration across the SC [30]. The blockchain technology can also be useful when it comes to creating lasting information transparency within a SC [31]. As such, we can conclude that many SCs evolve into ISNs based on the principles of co-creation and co-evolution. Such mechanisms are principally different from classical SC by requiring new characteristics. DT has become an important factor that stimulates various academic areas and affects practice, contributing to independent research streams. Research scholars study the antecedent implications and contingencies of these transformative innovations by exploring the usage of particular technology or digitalization in general. Companies are experiencing digital transitions to build new SC models. It is imperative to evaluate the impact of DT on different SC models to be able to react in an efficient way to strong shocks. The extra-ordinary events, in fact, go beyond a narrow understanding of SC management because it brings

the discussion to a micro level of SC elements in terms of information, technology and knowledge flow within and across sectors. Thus, configuring SCs is a crucial activity that can determine the success or failure of a company in emerging industries [32], and moreover, it can also determine market satisfaction and SC performance in terms of guaranteeing the delivery of goods and services to the clients. Despite their importance, methods for emerging industries to develop effective supply chain configurations are lacking. Stemming from the concept of ISN, we propose a maturity model for supply chain management. In this above described complex and uncertain scenario, the decisive challenge is the ability of SCs to have a competitive advantage along with proper answers in an efficient way to face the shocks. Thus, the application/integration of technologies activate immediate reaction processes which, while maintaining the performance in terms of production costs, delivery times and conformity of the products produced, generate new balances and new configurations, in internal processes and in the relationships between different actors of the supply chain. Specifically, we intend to adopt the theoretical lenses of viability, reactivity, resilience and antifragility [4], in order to identify the structure of SC that can be proposed. It is on these pillars of literature on which the present paper is based.

3. Opportunity to design maturity models for the supply chain: the LiSC Model

The specific objective of the work is to offer a significant state-of-the-art advancement, developing a new SC model. The approach consists of creating a matching between the literature on the SC and that on the Open Innovation (OI), in the perspective of DT, in order to develop for the companies a new paradigm that they adopt to react in an efficient way to shocks. This implies further challenges in managing the growing amount of knowledge and information flows, overcoming the concept of traditional SC Models.

3.1 Empirical analysis

Because the literature does not contain a complete list of SC characteristics to react in a "viable" way to important disruptions or crisis, we conducted an explorative qualitative analysis, through a case study methodology, since they can be considered particularly helpful when exploring the details of real-life and emerging phenomena [37]. The aim is to investigate how to overcome external shocks, in terms of: (a) managers' perceptions and willingness to adopt new SC models, (b) application of DT to the SC to design new SC models, (c) features of SCs. The qualitative analysis helped to model the construct and precisely identify its differences with respect to existing concepts. We propose the case study of DoTECH, an experimental initiative developed in Calabria (Italy) within a Smart Specialization strategy (S3) Thematic Platforms, for the detection and enhancement of the technological equipment present in a sample of companies belonging to the Smart Manufacturing Innovation Area. Companies involved in the DotTECH project are SMEs located in Calabria, a region with about 2 million inhabitants, with a GDP equal to 60% of the average in Italy and thus subjected to strong interventions by the local and the central government. Due to massive funding support by the Region, many companies bought very modern I4.0 machines but their use was very limited. The optimal use of these equipment overcomes the fragmentation of the production system. The case study investigated the propensity of entrepreneurs to share their technologies (and competencies) with others, in order to increase product innovation, improve process efficiency, overcome the unexpected crises and, finally, reach new markets. The big funding interventions allowed the diffusion of modern interconnected I4.0 machines, whose use was not pulled by the market but pushed by the policy. Thus, the actual machine use was not very intensive, generating the same situation of a crisis, in which industrial productivity is dramatically reduced. During the period between November 2017 and February 2018, 24 managers belonging to SMEs of the Italian manufacturing sector were interviewed. A short interview (almost 1 hour) was proposed to the managers with the aim to explore: their attitude to share technologies and competencies; their propensity to adopt DT in the SC, their need to create a SC with viability attributes, exploring also other additional elements.

3.2 Results

From the interview comes out that 21 managers (out of 24) demonstrated a propensity to share their technology with others, especially in the perspective to deal with unexpected demand. Each of them indicated the technologies they are available to offer. 101 industrial machineries were proposed, mostly used for metal plastic deformation and removal processes. The interviewer offered a list of possible variables that can influence firm strategies (5=Very high; 1=Very low) and that are listed below:

Table 1. Variables and average score of the firms' answers.

Variable	Average Score
Localization	2
Supplier turnover	3
Supplier training	3
Manufacturing flow management	3
Information system	4
Logistics	4
Virtuality	4
Importance of customers	4
Continuous improvement programs	4
Customer relationship management	4
Standardization/customization	5
Available capacity	5
Worker availability	5
Technology availability	5
New products creation	5
Supply quality management	5
Open system context	5
Co-development of new product with other actors across the SC	5
Exploit unused technologies and unused Knowledge	5
Overcome lacks technologies and Knowledge	5

From the answers comes out that according to most of the managers, some of their plans are oversized and frequently they are not able to fully employ all the machineries; at the same time they lack some machineries that they need to exploit their processes . To beat these difficulties, they suggest to enac new form of supply chain, able to exploit unused technologies and unused Knowledge, to overcome lacks and to better exploit their own plans. Most of the interviewed managers suggested to be interested to create a virtual catalogue of technological equipment owned by Calabrian companies, aimed at promoting forms of cooperation, products, services or processes also for access to new markets. The explorative qualitative analysis revealed, in fact, that they have the need to change the structure of SC (topology and dimension to create new pathways to market), even if this topic is not always well assessed or understood within organizations. Most of the managerial practices are mainly related to time-performance. Every firm wants to satisfy the demand on-time to increase customer satisfaction and loyalty as well as a competitive advantage. Thus, the interview investigated some novelties: knowledge and technology available, latent and potential needs to be satisfied, new product creation, new markets to target. When discussing innovation performance, the managers voiced doubts about their ability to adequately perform under unexpected conditions (Reactivity), but also their ability to withstand a disruption, or a series of disruptions, and recover the performance (Resilience). Although innovation with unexpected demand is difficult to achieve, some firms want to rich this performance. The wish to satisfy customers is always the driving motivation, under unexpected events. If it is true that the customer is the main driver, firms obtain higher competitive advantage only by adopting a broader perspective that embraces customer satisfaction as well as firm performance under unexpected demand fluctuation. Finally, the qualitative analysis revealed the managerial practices to overcome unexpected events, by adopting Digital Transformation. From the analysis come out some elements useful to reconfigure the SC. Specifically, we consider 4 dimensions: the structure, the processes, the technology and the performance.

Table 2. Qualitative SC analysis.

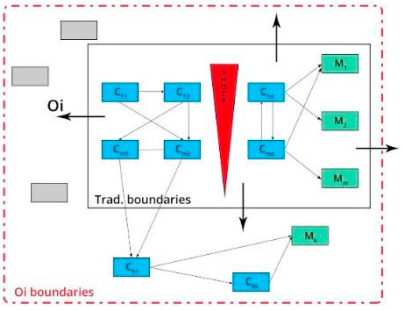
SC dimension	Drivers	Managerial practices
Structure	Collaborative manufacturing platforms	Open innovation
Structure	Collaborative supplier portals	Open innovation
Process	Open system context	Networking among nucleus of technologies
Process	Open system context	Human-machine collaborative networks
Process	Self-healing SC	Dynamic networks where the Topology depends on context conditions
Process	High level of customization	Co-development of new product
Technology	Modularity	Share Nucleus of Technology as a micro level entity
Performance	SC performance	Viability , Resilience, Antifragility,Reactivity,Customization, Product innovation rate
Performance	Operations' performance	Bottlenecks reduction, Increase of Manufacturing Productivity, Reduction of capacity utilization rate

3.3 The LISC paradigm

From the empirical analysis comes out that there is the need and the possibility to deconstruct the SC, by considering some core characteristics like: connections, technologies, dynamicity, performance. It would be metaphorically transformed in a "liquid" SC, according to the Bauman paradigm: "*modernity, heavy and solid, turns into light and liquid*". Enabling technologies become key connections and management tools and guarantee the creation of bonds in an extremely open context. In a "liquid" system [33], the necessary skills to complete the development processes of innovations may not all be present in a single company, therefore, the ability to find adequate skills also outside become strategic, creating the basic conditions for the implementation of network relationships. In these increasingly complex and uncertain contexts, modern Supply Chains (SC) operate, being SC both a flow of raw materials and a flow of information. Besides, digital transformation through the enabling technologies is finally making the links of the chains always more unstructured but at the same time interconnected or potentially interconnected, affecting complexity and uncertainty. Open innovation enlarges the normal SC dimension putting-in new actors which can constitute new technological nuclei, as defined in the following. Firms are experiencing the switch from a heavy and solid structure to a light and liquid modernity, coherently with Bauman's theory. The new paradigm that is being proposed is called Liquid Supply Chain (LiSC), that can be considered a maturity model of supply chain. Going beyond the concept of "stable network", it proposes the concept of "technological nucleus" (TN) for the creation of dynamic and customized networks [34]. TN is the basic element of the SC, which can be a machinery, a firm, a particular skill, in general a capacity. The new model is based on several TN and take on a topology dependent on context conditions (such as liquids), ensuring the generation of proper pathways to reach the market, even if different respect to the previous ones.

The Liquid Supply Chain model is based on a configurable network of technologies nucleus; moreover, it is not a sequential model but a co-developed one. The connection between the nuclei is supported by the management software (ERP) on one hand and logistics on the other, taking into account that the movement of semi-finished products in a cloud system becomes one of the crucial nodes within the liquid supply chain paradigm. When we live a stable market condition, the SC assumes a stable configuration. When an extraordinary event upset the market, SC can be dramatically affected as represented in Figure 1.

Figure 1. Representation of LiSC model



The scenario in the Figure 1 illustrates the LiSC Model as an evolution of the Intertwined Model [35]. C_{mn} represents the single component *n* of the supply chain *m*, which now is no more necessarily a firm since they are deconstructed, but a technological nucleus, therefore a single machinery, a capacity, a process, an operation center…The M_m unities, on the other side, indicate all the *m* possible markets. The red wedge represents the disruptive event, which as a shock literally breaks the chains, inducing them to find new configurations within their traditional boundaries or outside, through Open Innovation processes. As an example, we can refer to the boundary closing. The new SC has to allow four main characteristics: reactivity, resilience, antifragility and viability (35). In these cases, Open Innovation can help to enlarge the SC influence calling in the game new and unexpected players able to interpret the SC in a new way. If a new pathway allows to reach the market (both the original one or another), the SC has also the characteristic of antifragility. In a mathematical representation, it is possible to describe the LiSC model as follows:

$$\mathbf{G} = (\mathbf{V},\mathbf{A}) \tag{1}$$

where **V** is the set of nodes and **A** is set of arcs. Note that:

$$\mathbf{V} = \mathbf{C} \cup \mathbf{M} \tag{2}$$

where:

$$\mathbf{C} = \{C_{11}, C_{12}, \dots, C_{1n}, \dots, C_{m1}, C_{m2}, \dots, C_{mn}\} \tag{3}$$

is the set of nodes of the SC, where *m* indicates the generic standard SC and *n* represents its generic element.

$$\mathbf{M} = \{M_1, M_2, \dots, M_m\} \tag{4}$$

is the set of the nodes which are related to the markets. Considering the set **C** as an ordered list of nodes, with

$$|\mathbf{C}| = m \text{ x } n \tag{5}$$

and the set **M** such that:

$$|\mathbf{M}| = m \tag{6}$$

then:

$$|\mathbf{V}| = m \text{ x } n + m \tag{7}$$

The adjacency matrix **L** is indicated as follow:

$$\mathbf{L} = \begin{bmatrix} L_{11} & \cdots & L_{1,nxm} & \cdots & L_{1,nxm+m} \\ \vdots & \ddots & & & \vdots \\ L_{nxm,1} & & \ddots & & \\ \vdots & & & \ddots & \\ L_{nxm+m,1} & & & & L_{nxm+m,nxm+m} \end{bmatrix} \tag{8}$$

where

$$L_{ij} = \begin{cases} 1 & \text{if the arch } (i,j) \text{ exists} \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

If there is not at least one path that links a generic node C_{kk} to at least one market $M_{k,}$ it means that it needs to be reconnected to the cloud because otherwise it is not active. Stemming from the existing literature and considering the frontier model suggested by some authors, this new model is based on the network of technology nucleus according to a self-healing SC structure [35]. To provide a validation example, we can consider what is happened during one of the most acute phases of the Covid-19 emergency in Italy. The well-known sport store Decathlon™ had a strong decrease in selling during the lockdown. Among the selling products, also diving masks were included. The strong request of lung-ventilators activated an open innovation call, enlarging the dimension of the LiSC, which taken to the production of a new accessory able to change the final market of the diving mask. A new valve system, properly designed and built by additive manufacturing technology, allowed to change diving musk into lunges ventilator mask, targeting a new market in a very critical conjuncture. The SC became liquid and, at the same time, both reactive and anti-fragile. According to the new paradigm, companies will make their production surplus available at real-time and, at the same time, anyone will be able to take advantage of that made available in the ecosystem. It will be possible to react positively to shocks, drawing various advantages, including coping with excess demand, optimizing the productivity of its resources and drawing on external resources in a simple and immediate way. The LiSC Model, in fact, has the characteristic to significantly increase the viability of the whole supply chain eco-system, relying on the provision of the digital technologies which are expected to be among the pillars of this new model. In fact, technologies can be used and implemented to manage open innovation processes through easier access and sharing the knowledge created and transferred. For the ability to respond resiliently to shocks and crises, this new model works through the application/integration of technologies and establishing, if necessary, new configurations both in internal processes and in the relationships among the different actors of the supply chain. Furthermore, there would be several advantages for businesses, including the optimization of firm productivity in terms of resources. It makes it possible for companies to make profits from periods that would have been downtime or underpowering and at the same time to cope with excess demand, being able to expand firm production capacity by drawing on resources that otherwise would not have been available. In fact, it gives to each firm the opportunity to offer the own unused technology and the own unused knowledge in order to satisfy the needs of other firms that lacks resource to satisfy the market. At the same time, it gives to a single firm the opportunity to overcome lack of technologies and knowledge, by getting the best technology in the supply chain system. Through this model, it is possible to co-create and co-develop new products that didn't exist before, but that can solve the market needs. The main differences and similarities with the frontier model of Intertwined supply networks consider both the strategy and the structure. A new supply chain model implies also the identification of suitable management tools that can support all the actors involved in the open innovation process. The models are summarized in Table 3.

Table 3: Comparison between SC models

Dimensions	**Intertwined supply networks (ISN)**	**Liquid SC**
Referred Theory	Ecological modelling [38]	Liquidity [33]
Strategy	Co-creation and co-evolution of products	Co-creation and Co-development of new products
Structure	Firms can play different roles simultaneously: suppliers, focal firms, and Consumers (Entities)	Technology nuclei (Entities)
Structure	Dynamically changing structures	Self-reconfiguration stimulated by Open Innovation
Structure	Collaborative manufacturing platform	Collaborative manufacturing platform
Performance	Viability	Viability, Reactivity, Resilience Antifragility

4. Conclusions

Based on the state of the art, the paper offers a significant scientific and technological transfer progress. From a scientific point of view, it proposes a strong coexistence of the concepts of Open Innovation (OI) and Supply Shain

(SC), with the support of Digital Transformation (DT) which feed a new perception of innovation. We are moving in the direction of greater co-creative and flexible collaboration between the players of the innovative ecosystem, proposing a new SC management paradigm based on dynamic technological entities, in an increasingly open context. From an application point of view, future researches will propose a cloud company model coherently with some authors that allows companies to systematize their technological and knowledge resources and their production processes (entities). The goal of the LiSC model, in fact, is even the separation of the concept of design from the physical one (the factory), and subsequently the concept of the factory itself from that of the proprietary factory, realizing production processes entirely "*in cloud*". New technologies to connect capacities (technological nuclei), together to Open Innovation and Liquid SC may constitute a brilliant mix to react to crisis and generate new opportunities when market condition changes due to a shock or, why not, the less dramatic normal fluctuation.

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