Methodological Please insert the below note as article title footnote. "Author names are listed in alphabetical order." approaches to supply chain design

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This paper reviews methodological approaches to the design (or redesign) of the supply chain (SC), including comprehensive approaches (proposals concerning the entire process of designing the SC) and those that deal with four specific aspects of the process (definition of the SC objectives, reverse SC, finance, and generation and use of scenarios) that have a decisive influence on the whole design of the SC. The comprehensive approaches include those based on typologies of products, markets and SCs and those that propose a succession of the stages to follow through the design process. The discussion shows that the use of typologies is not adequate to face SC design and that the methods proposing a succession of stages may suit, provided that they are developed and presented in a manner appropriate to their use for practitioners. The discussion leads also to suggest several research lines.

Keywords

supply chain design

supply chain network
supply chain design methodology
design of production systems
supply chain management

1. Introduction

This paper reviews methodological approaches to the design (or redesign) of the supply chain (SC). We have taken into account the proposals concerning the entire process of designing the SC (which we call comprehensive approaches) and those that deal with four aspects of the process that have a decisive influence on the whole design of the SC and in which the fact of referring to the SC, instead of to other simpler logistics or production systems, involves a distinguishing feature. Specifically, we examine the definition of the objectives of supply chain, the reverse SC, financial aspects, and the generation and use of scenarios, which because of their complexity, when it comes to SCs, require a deepening from the methodological point of view.

The terms Supply Chain and Supply Chain Management (SC/SCM), since their inception in 1982 (Oliver and Webber 1982), have come to achieve a dominant role as integrative concepts concerning the broad field of managing creating value systems. Although there is not a unique recognised closed definition of supply chain (Stock and Boyer 2009; Corominas 2013) it is generally accepted that a supply chain is a network of entities that collaborate in order to obtain, deliver and maybe recover a product or a set of products and that the management of a SC concerns the people, material, information and financial flows between the entities belonging to the SC and the operations that have to take place in some of them; according to Stadtler (2002) and Stadtler and Kilger (2005), which state that there can exist a 'natural' leader or a steering committee, usually one of these entities (company, public institution, NGO, association, club, foundation, etc.) leads the SC, i.e. decides about its objectives and configuration, the criteria to assess the performance and establishes the main rules concerning its running (this entity is called the dominating unit – Chandra and Grabis 2007 –, the focal firm – Wagner and Neshat 2010 – or the leading entity – Corominas 2013 –).

The reasons for the success and the uninterruptedly increasing use of SC/SCM are manifold. Among them, it can be pointed out, first, that the concept of SC is an updated attempt to give a systemic view of activities and flows that occur when supplying, producing, distributing and recovering one or more products and, secondly, that they establish the appropriate framework for describing, analysing and solving the new problems that have emerged as a consequence of the evolution of the increasingly complex real creating value systems.

SC design (SCD) or redesign (many authors use the expression 'supply chain network design or redesign' – SCND –, sometimes in a slightly more restrictive sense: Lakhal et al. 2001; Dotoli et al.

2005; Santoso et al. 2005; Sha and Che 2006; Laínez et al. 2009; Akçalı, Çetinkaya, and Üster 2009; Alumur et al. 2012; Carle, Martel, and Zufferey 2012; there is even a paper – Lakhal, Martel, and Oral 1999 – that deals with 'network companies' barely mentioning supply chains) is a strategic problem, which refers to the structure of the SC throughout a certain number of years, and whose solution influences strongly the performance of the SC. According to Chopra and Meindl (2016) and the previous editions of their book, the design of a SC comprises the decisions regarding the number and location of production and warehousing facilities, the amount of capacity at each facility, the assignment of activities to resources (including the option between in-house and outsourcing) and supplier selection for sub-assemblies, components and materials, the assignment of market regions to one or more locations, the selection of modes of transportation and the type of information system to be used. This coincides substantially with the definition of SC configuration in Chandra and Grabis (2007) as the determination of the size and location of the units to be included in the SC and the links among them. On another hand, in Melnyk, Narasimhan, and DeCampos (2014), the terms 'SC design' and 'SC architecture' are used interchangeably. In the present paper, as it is common in the literature, we will consider the terms design and configuration as equivalent.

A certain number of papers include also definitions of SCD. For Harrison (2001), SCD is the process of determining the SC infrastructure (plants, distribution centres, transportation modes and lanes, production processes, etc.). Meixell and Gargeya (2005) and Hammami, Frein, and Hadj-Alouane (2008) adopt that of Chopra and Meindl in the 2004 edition of their book and that in Klibi and Martel (2013) is very similar. The definition in Klibi, Martel, and Guitouni (2010) is close to that of Klibi and Martel (2013), with the important remark that the decisions involved in SCD are of strategic nature. Melnyk, Narasimhan, and DeCampos (2014) see the SCD as a dynamic concept that comprehends three levels of factors, namely, influencers, design decisions and building blocks.

From our point of view, the design process of a SC has to comprise all the decisions that are necessary to define its configuration. Therefore, it must include the specification of the objectives of the SC and the criteria to assess its performance, besides, as stated in the above definitions, the identification of the elements or the type of elements that will be members of the SC and the relations between all these elements (i.e. the configuration of the SC network).

Being a strategic decision, the design of the SC has long-term implications and may involve important investments. Given its paramount importance and its complexity, SC design requires a method, understood as a series of ordered steps with guidelines and tools to facilitate their implementation (Chandra and Grabis 2007; Corominas et al. 2015). However, the methodological contributions to the design of SCs are still scarce among the huge amount of papers devoted to SCM, even in those dealing explicitly with SC design. We hope that the present paper will contribute to make easier the task of academics and practitioners interested in SC design and to stimulate new contributions.

Our focus is primarily on methodological proposals for the design (or the configuration) of the SC. We refer, therefore, to overall or comprehensive methodological proposals, i.e. to frames that consider all decisions involved in designing the SC.

Additionally, as it is said at the beginning of this section, papers presenting or dealing with concepts not included or not sufficiently stressed in the published methodologies and that we deem relevant for the design process are also considered in the review.

Therefore, our approach is different from that of previous reviews concerning SC because they regard a specific aspect of the SCs (e.g. Maestrini et al. 2017; on SC performance measurement systems; Farahani et al. 2014; on competition between SCs) or they focus on the formulation of mathematical programming models for the design of the SC. However, we think, according to Corominas et al. 2015,; that the formulation and resolution of a mathematical model cannot be identified with a method for designing SCs, because, as many important assumptions have to be taken prior the formulation of the model, a method must include a certain number of steps preceding the model, if any. The mathematical model, although being necessary most times, is only one element of any method concerning SC design and it has to be placed in an appropriated frame, as in Lakhal, Martel, and Oral (1999) or Vila, Martel, and Beauregard (2006). Consequently, the papers consisting basically in the presentation of a model, either generic or for a particular case, are not the subject of the review unless they contain some element that we consider relevant to our purpose. Reviews of the model-based literature are found, e.g. in Beamon (1998), Goetschalckx, Vidal, and Dogan (2002), Meixell and Gargeya (2005) and Shen (2007). Other papers deal with models oriented to specific kinds of SC or of decisions (Melo, Nickel, and Saldanha-da-Gama 2009; relating facility location models; Lambiase et al. 2013; Sharma et al. 2013; and Zandi Atashbar, Labadie, and Prins 2017; on biomass SCs; Brandenburg et al. 2014; on sustainability aspects in the forward SC; Pires Ribeiro and Barbosa-Povoa 2018); and Lemmens et al. 2016, on vaccine SCs).

The layout of the rest of this paper is as follows. The method of exploring the literature is described in Section 2. Sections 3, 4, 5, 6, and 7, respectively, deal with comprehensive approaches, the definition of the SC objectives, the design of the reverse SC, the financial aspects, and the generation and use of scenarios. Section 8 closes the paper with the conclusions and the suggested research lines.

2. Research method

To achieve the objectives of this paper it was necessary to identify all relevant literature describing methodologies for the design or redesign of SCs as well as papers dealing with concepts, tools, decisions and relevant elements to be considered for the design process.

The stages of the method applied for conducting this literature review are described below.

(1)

Formulation of the research question to be addressed: Which are the methodological contributions (steps with guidelines, tools, decisions involved, and relevant elements) to the design or redesign of SCs?

(2)

Identification of the relevant literature concerning methodological issues for SC design. We conducted an advanced search in the Web of Science database of the Institute for Scientific Information (ISI) sorted by critical keywords: 'supply chain design' AND 'method*'.

The search was refined by specifying 'article or review', 'English', and 'Operations Research Management Science or Engineering Manufacturing'. No time limitations were established.

Additionally, we looked for the references of studies found through the database search, AQ2 some reference books (e.g. Harrison 2004; Chopra and Meindl 201607; Watson et al. 2014; Chandra and Grabis 2016), conceptual papers such as Corominas (2013), and the papers citing those works.

(3)

Document selection. Based on the content of the summaries and, when necessary, full texts of documents, we eliminated those that did not address our central research question.

(4)

Analysis and discussion.

(5)

Summary and report of the results. As a result of the analysis carried out, the literature was organised according to two main groups: approaches based on typologies, and approaches based on a succession of stages.

3. Comprehensive approaches

We classify the proposals concerning the whole process of designing the SC into two groups: those based on typologies of products and SCs (Subsection 3.1) and those that present an orderly succession of stages to guide the process (Subsection 3.2).

3.1 Approaches based on typologies

Essentially, these approaches propose typologies for products and SCs and a correspondence between types of products and types of SCs.

The first proposal of this kind appeared in Fisher (1997), where a distinction is made between *physical efficient* and *market responsive* SCs to match *functional* and *innovative* products, respectively. Once the product type is identified, the type of SC is determined consequently. Functional products have stable, predictable demand, low variety, and long life cycles. Conversely, innovative products have unpredictable demand, high variety and short life cycles. If the product is functional, the SC has to be physically efficient (i.e. capable to supply demand efficiently, at the lowest possible cost). Conversely, if the product is innovative, the appropriate SC is a market responsive one (i.e. that can respond quickly to unpredictable demand in order to minimise stock-outs).

A number of researchers place their work in the frame defined by Fisher and in some cases contribute to its development (Lamming et al. 2000; Ramdas and Spekman 2000; Lee 2002 – in which four types of SC are considered: efficient, risk-hedging, responsive and agile–; Wong et al. 2006).

Others test Fisher's model, with not coincident results. The analysis of Li and O'Brien (2001) confirms partially Fisher's approach in a slightly modified version. Selldin and Olhager (2007) find some statistically non-significant relation between product types and SC types, according to Fisher's classification. The findings of Qi, Boyer, and Zhao (2009) are substantially coherent with Fisher's model. Conversely, Lo and Power (2010) conclude that the association between product nature and SC approach is not significant and adduce, among the reasons why this happens, the changes in the market, such as increased competition, increased demand variability, increased number of customer specific products and shorter product life cycles.

Some papers (e.g. Naylor, Naim, and Berry 1999; Mason-Jones, Naylor, and Towill 2000; Aitken, Christopher, and Towill 2002; Christopher and Towill 2002; Vonderembse et al. 2006) propose a SC typology similar to Fisher's with, however, a different terminology, which in fact is nowadays predominating: lean and agile SCs, respectively.

Naylor, Naim, and Berry (1999) suggest that the agile SC is best suited to satisfying a fluctuating demand in terms of volume and variety of products. If the variability in both volume and variety of products is low, a lean SC is proposed. However, they do not give indications for a combination of high (low) variability in the volume of the demand and low (high) variability in the product mix.

Mason-Jones, Naylor, and Towill (2000) distinguish between commodities and fashion products (characterised, respectively, by predictable and unpredictable demands) and consider that they suit, respectively, to lean and agile environments.

Vonderembse et al. (2006), however, associate lean SCs to standard products (whose demand, which tends to be stable, can be forecasted accurately) and agile SCs to innovative products (characterised by great variety, short life cycles and unpredictable demand). The authors point out that agile environments require partners capable of working jointly on research and development, while lean SCs require suppliers working under the principles of lean manufacturing.

The authors that use the terms lean and agile do not attribute always exactly the same meaning to these words. Generally leanness means developing a value stream to eliminate all kinds of waste (including time), and to ensure a level schedule (Naylor, Naim, and Berry 1999). Therefore, a lean SC tries to achieve internal manufacturing efficiencies, and setup time and cost reduction (Vonderembse et al. 2006) and tends to simplify and streamline the SC network, providing a high level of standardisation and specialisation (Chandra and Grabis 2016).

In contrast, agility is concerned primarily with responsiveness, the ability to respond rapidly to changes in demand, in terms of both volume and variety (Christopher 2000), to match supply and demand in unpredictable markets (Christopher, Peck, and Towill 2006). Accordingly, agile SC is market sensitive, and capable of responding to real demand; it is virtual and network-based; and capable to achieve integration among SC partners to react to the changes (Christopher 2000). Christopher and Towill (2001, 2002) state that a critical attribute that distinguishes agility is service level (availability). Therefore, there is not a consensus on the concept of agility. Note, moreover, that dealing with (i) fluctuations in the volume of demand, (ii) changes in the product mix, (iii) short life product cycles and (iv) high levels of availability require different capabilities and characteristics of the SC (flexible working time organisation, polyvalence of the working force, R&D and excellent inventory management accompanied by short replenishment lead-time) and that these requirements are not always present together.

Table 1 summarises the attributes of agile SCs according to diverse authors. It shows that only two couples of papers (Naylor, Naim, and Berry 1999 and Christopher 2000; on the one hand, and Christopher and Towill 2001 and 2002, on the other hand), out of eight, coincide.

Table 1. Attributes of agile SCs.

	Short delivery lead time	**Short replenishment lead time**	**Short product life cycle**	**High variability in volume (production rate)**	**High product variety**	**High availability (service level)**
Fisher (1997)	√		√		√	
Naylor, Naim, and Berry (1999)				√	√	
Christopher (2000)				√	√	
Mason-Jones, Naylor, and Towill (2000)	√					√
Christopher and Towill (2001, 2002)	√		√	√	√	√
Christopher, Peck, and Towill (2006)		√	√	√		√
Vonderembse et al. (2006)	√		√	√	√	

Christopher and Towill (2002) suggest a three dimensional classification to match the SC design to market needs. The variables they consider are products (standard or special), demand (stable or volatile), and supply lead times (short or long). This generates three feasible SC designs: lean (predictable demand for standard products with long lead-time), innovative agile (volatile demand for special products with short lead-time), and top-up agile (for quick response to top-up standard products with an unexpected demand and short lead-time).

Christopher, Peck, and Towill (2006) suggest that replenishment lead-time must be included in any useful taxonomy, that is, the time it would take the system to respond to an increase in demand if materials (parts or components) had to be sourced or manufactured. They classify markets according to the predictability of the demand, and propose a classification scheme with four generic settings: continuous replenishment (predictable demand and short lead-time), agile quick response (unpredictable demand and short lead time), lean, planning and execution (predictable demand and long lead time), and leagile production/logistics postponement (unpredictable demand and long lead time).

Chandra and Grabis (2016) propose four main SC approaches: lean, flexible, agile and service-oriented. Therefore, they distinguish between flexible and agile SCs. Flexible SC strategy addresses uncertainties associated with SC operations and demand uncertainty. Agile SCs combine flexibility and adaptability by reconfiguring the SC network and introducing substantial changes in a proactive manner. In our opinion, it should be necessary to expand and complete these definitions, for a better understanding of the characteristics of flexible and agile typologies, as well as in what circumstances it is more appropriate to use each of them. Service-oriented type is added to emphasise the emerging importance of services and for provisioning of required capabilities and resources on-demand from service providers; this approach focuses on the electronic movement of information and delivery of services, instead of physical movement of products.

Hilletofth (2012) considers that most of the previously exposed approaches are too simplistic, because they imply to select between two SC solutions for the whole company, and points out that they regard markets as homogeneous instead of considering that customers are increasingly seeking individual solutions to their needs.

Although lean and agile SCs often appear as opposing paradigms, some researchers have suggested that they can be combined in a variety of ways to create so-called leagile (Naylor, Naim, and Berry 1999; van Hoek 2000; Hilletofth 2012) or lean-agile SCs (Mason-Jones, Naylor, and Towill 2000; Christopher 2000; Christopher and Towill 2001, 2002; Christopher, Peck, and Towill 2006; Vonderembse et al. 2006). These hybrid approaches result from combining lean and agile paradigms (Naylor, Naim, and Berry 1999; Mason-Jones, Naylor, and Towill 2000).

Of course, to join leanness and agility is always desirable, but the question is in which settings this is possible. Christopher (2000) says that hybrid SC approaches can be applied when, within a mixed portfolio of products and markets, the demands of some products are stable and predictable, and the demands of other products are not. Christopher and Towill (2001) state that, when product ranges can be separated according to volume and variability and/or the decoupling concept can be applied, there is an opportunity for employing hybrid approaches.

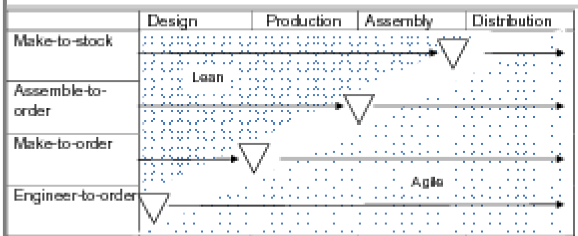
We think, however, that a distinction has to be made between a hybrid SC and a set of two or more SCs using different approaches. Differentiation (Hilletofth 2012) means to identify separate value streams, and to configure different SC approaches for different market segments. Strictly speaking, conversely, a hybrid SC would consist of two complementary parts designed according to two different approaches.

In this vein, the customer order decoupling point (the so-called order penetration point) is acquiring attention as an important factor in the SCD (Collin, Eloranta, and Holmström 2009; Olhager 2010 and 2012). According to the definition of Sharman (1984) is the point where product specifications typically get frozen. It is the stage in the value chain for a product where customer orders are allocated to the product supply (Collin, Eloranta, and Holmström 2009), the point at which real demand penetrates upstream in a SC and is made visible (Christopher 2000).

The inventory at the decoupling point is a strategic stock-point that determines lead times (Hammami, Frein, and Bahli 2017) and capacity availability for delivery (Olhager 2012). Companies can hold inventory in this point and only complete the final assembly or configuration when the precise customer requirement is known (Christopher 2000). The order penetration point divides the material flow that is forecast-driven (upstream) from the flow that is customer order-driven (downstream). The concept of postponement, delaying certain SC activities until orders are received, allows companies to use lean methods up to the decoupling point and agile methods beyond it (Christopher and Towill 2001; Olhager 2010), and create a responsive and cost-efficient SC, a leagile SC.

Different manufacturing situations such as make-to-stock, assemble-to-order, make- to-order, and engineer-to-order, relate to different positions of the decoupling point (Figure 1).

Figure 1. Different customer order decoupling points (based on Martínez-Olvera and Shunk 2006; Hilletofth 2009; and Olhager 2012).



Collin, Eloranta, and Holmström (2009) present two applications of the approach based on typologies, corresponding to two leading SC companies that have used them to address both product characteristics and customer differences in SC re-design. In both cases, the method consisted of the following four steps: (i) decide whether products are functional or innovative, (ii) understand customer's demand chain and stretch for downstream demand visibility, (iii) design alternative SCs, and (iv) select the best SC for and in collaboration with each customer.

In addition to the research addressed to provide a conceptual understanding of SC agility, several studies have investigated the factors, enablers, or drivers that contribute to achieving SC agility (e.g. AQ3 Sangari, Razmi, and Zolfaghari ~~et al.~~ 2015), and other studies have focused on performance outcomes associated with SC agility (e.g. Gligor, Esmark, and Holcomb 2015; Tarafdar and Qrunfleh 2017).

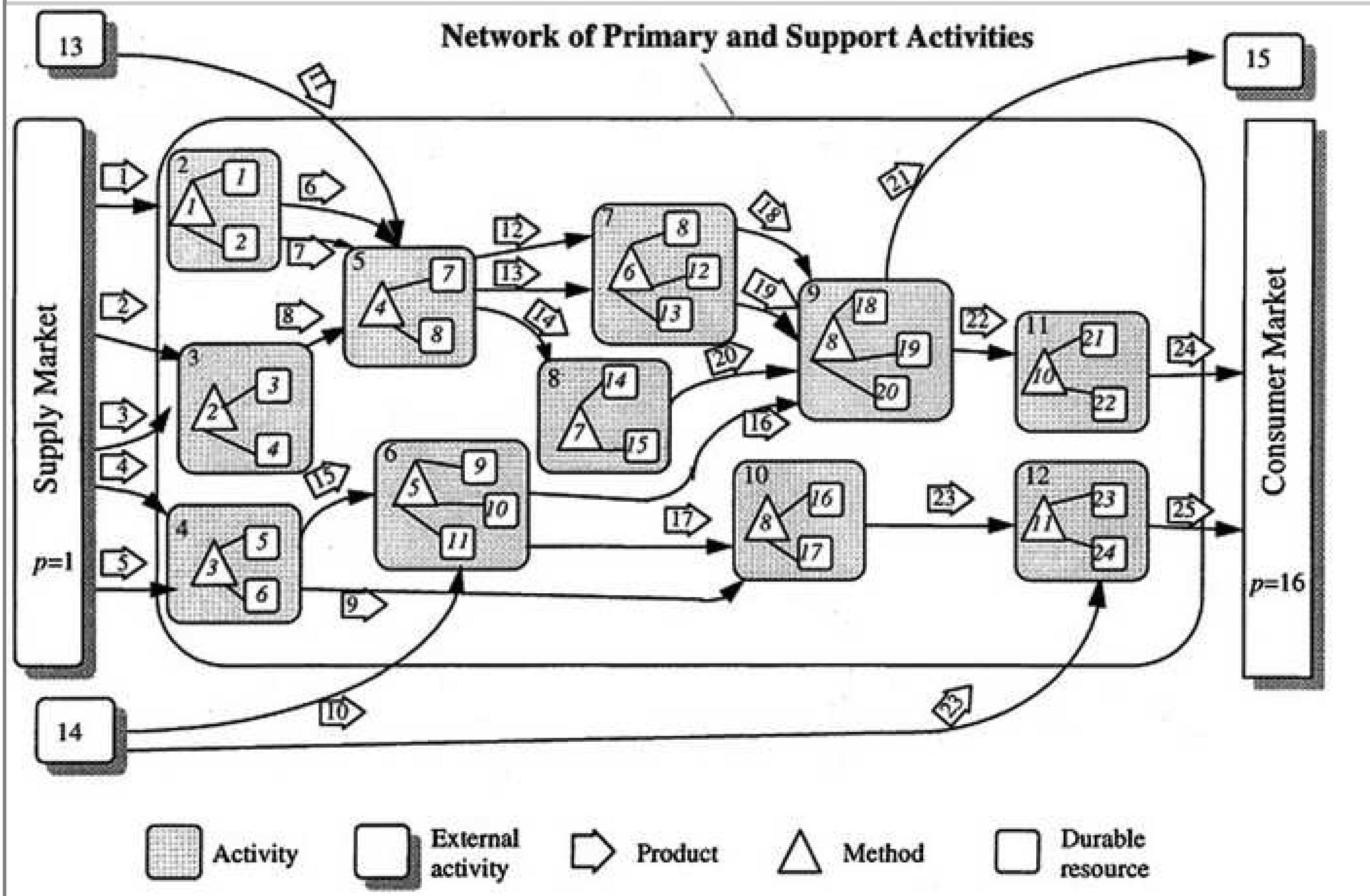
3.2 Approaches based on a succession of stages

Although some papers dealing with approaches based on typologies (Christopher and Towill 2001; Hilletofth 2012) outline a set of steps in order to apply the corresponding approach, the kernel of these proposals is the identification of the type of product and the ensuing type of SC. Therefore, we have not included them in this subsection.

To the best of our knowledge, the first proposal of a method that consist of a series of steps was configured in a set of related papers, initiated by Lakhal, Martel, and Oral (1999). That article proposes a methodological framework that starts with the representation of product-market chains by means of activity graphs, which are the main constituent of their proposal. In the activity graph (Figure 2), specific symbols and modelling constructs are used to characterise the technological and managerial requirements that are necessary to deliver a consumer product to a market. Four elementary components are considered: durable resources, methods, activities and products (the latter include inputs, intermediary and outputs, and may be physical or not, like information, knowledge and services). The set of *elementary* components is defined at the most detailed meaningful level that is required. The activity graph represents a complete product-market chain, and shows in a sequential order the elementary activities required to produce and deliver a product to a specific market. Three main categories of activities are defined: time, which preserves products in time, such as stores or files; space, which moves products in space, such as delivery or communication services; and form, which changes the nature of the products through processing, assembly operations or decision-making. In order to represent a complete activity graph for a given industrial context, it is necessary to obtain detailed information of the processes that take place in it. Note that using the concept of activity graph does not require a tiered structure of the SC, what is relevant because in general the element of a SC cannot be assigned univocally to a level.

Figure 2. Activity graph. Reprinted from European Journal of Operational Research, 118, Lakhal, S., Martel, A.~~I~~, Oral, M. and Montreuil, B., Network companies and competitiveness: A framework analysis, page 281, Copyright (1999), with permission

form Elsevier.



To evaluating the design of the product-market chain, it is necessary to define the attributes associated to its components (e.g. costs, availability, quality and flexibility). The attributes characterising products are associated with the arcs of the graph. The revenues are modelled by value functions. Lakhal, Martel, and Oral (1999) gave general orientations to derive afterwards a mathematical model to find the optimal mapping of sourcing, manufacturing warehousing and distribution activities that constitute the company's product-market chain. Lakhal et al. (2001) subsequently derived a static mathematical model from the activity graph and proposed a heuristic to solve it. SC models based on activity graphs were afterwards proposed by Vila, Martel, and Beauregard (2006) and M'Barek, Martel, and D'Amours (2010), as it is pointed out in Carle, Martel, and Zufferey (2012).

Vila, Martel, and Beauregard (2006, 2007) close the elaboration of this methodological framework. In Vila, Martel, and Beauregard (2006) the authors develop a mathematical model based on an activity graph to design international production-distribution networks of divergent process industries (i.e. industries manufacturing several products from a single raw material such as in the lumber or meat industries) and propose a generic methodology that involves five steps:

(1)

Definition of product-markets, sourcing context and planning horizon.

(2)

Definition of product families and representation of a production-storage activity graph.

(3)

Definition of potential network resources, and the input-output quantities of production activities for a given technology (recipes).

(4)

Definition of relevant revenues and expenses associated to the network design and activity decisions.

(5)

Formulation of a mathematical model to map the activity graph onto the potential network resources.

In essence, the four first steps define the company's production-distribution network, while the last step of the methodology optimises results. The manufacturing process is represented by a directed multigraph of production and storage activities. Set based constructs, as well as material and financial parameters, are defined to represent the internal and external business environment, the technology opportunities available to increase competitiveness, as well as the financial information required to evaluate these opportunities in an international context. Finally, a mathematical programming model is formulated to enable the optimal mapping of activities to locations.

An extension of this model is proposed by Vila, Martel, and Beauregard (2007) to consider probabilistic market opportunities.

Chandra and Grabis (2007) proposed a SC configuration methodology that present again, with some minor modifications, in the second edition of their book (Chandra and Grabis 2016). The authors state that this methodology is applicable for new SC development and for reconfiguration of the existing SC in response to changes in the environment and in the business strategy (e.g. new product development). It consists of the eight steps outlined below:

(1)

SC strategy updating: to define the objectives and the scope of SC configuration in alignment with the SC strategy.

(2)

Conceptual modelling: to establish a formal definition of the considered SC design problem and to collect the relevant data; conceptual models are used for describing the objectives, concepts and processes of the SC design.

(3)

Experimental planning: to select the appropriate procedures for modelling and analysing the SC configuration problem, to identify the relevant experimental scenarios, and to define the experimental plan to perform.

(4)

Preselection of candidate alternatives.

(5)

Modelling and analysis: use of qualitative and quantitative SC design models.

(6)

Decision-making, using multi-criteria and group decision-making methods.

(7)

Implementation of the physical location of SC units and the specific investments required.

(8)

Monitoring and evaluation.

A hierarchical top-down methodology for the design of the SC is proposed in Corominas et al. (2015). It is called SCOP (SC Outline Process) and consists of five main stages:

(1)

Definition of the object, environment and objectives of the SC. The most relevant scenarios are derived and the planning horizon is determined.

(2)

Definition of the SC macrostructure (i.e. the activity blocks and their relations, including reverse logistics), which may be formalised by means of an M-graph.

(3)

Definition of the SC mesostructure (i.e. the product structure and the production process). An m-graph can be used to represent the set of activities and their relations. Alternative options regarding procurement-production, distribution, collection and reprocessing are considered.

(4)

Definition of SC microstructure (i.e. facilities, sources of demand and means of transport). A μ-graph is derived from every m-graph generated at stage 3.

(5)

Choose of final SC configuration and formulation of protocols to detect and correct incidents and disruptions.

The proposal of Chandra and Grabis (2016) is a very general frame, which can be applied to the design of a variety of systems, different from SCs. It has not many relevant similarities with the other two approaches. Conversely, as its authors point out, SCOP shares with the framework of Lakhal, Martel, and Oral (1999) the use of graphs as an important tool representation and, mainly, the fact of separating the description of the procurement-production-distribution process from the description of the (potentially) available resources and mapping the activities into resources. Both approaches coincide also in the consideration of the mathematical models as an optimising tool to be used only after having adopted relevant decisions on the configuration of the SC. The main difference is that

SCOP adopts a top-down approach in contrast with the bottom-up approximation proposed in Lakhal, Martel, and Oral (1999).

On the other hand, SCOP generalises to the activities of procurement-production, collection and reprocessing the idea of Chopra and Meindl (2016), concerning distribution networks, offering to the SC designer a list ~~relation~~ of options, a set of criteria to evaluate them, and generic recommendations for selecting an option from the available list according to the characteristics of the product and the market.

Table 2 provides an integrated view of the main characteristics of the methodological frameworks discussed in this subsection.

AQ15 Table 2. Comprehensive methodological frameworks based on a succession of stages.

Comprehensive methodological frameworks	Design approach		Methodological tools						
	Bottom-up	Top-down	Activity graphs	Scenarios	Mathematical programing models	Conceptual models	Simulation and hybrid approaches	M
Lakhal, Martel, and Oral (1999)	x		x					
Lakhal et al. (2001)	x		x	x	x		x	
Vila, Martel, and Beauregard (2006)	x		x		x			
Corominas et al. (2015)		x	x	x	x			
Chandra and Grabis (2016)		x		x	x	x	x	

Comprehensive methodological frameworks	SC design decisions						
	Production options	Distribution options	Collection options	Reprocessing options	Means of transport options	Facility locations	Supplie selectio
Lakhal, Martel, and Oral (1999)	~~x~~	~~x~~				~~x~~	~~x~~
Lakhal et al. (2001)	x	x				x	x

Comprehensive methodological frameworks	SC design decisions						
	Production options	Distribution options	Collection options	Reprocessing options	Means of transport options	Facility locations	Supplie selectio
Vila, Martel, and Beauregard (2006)	x	x	~~x~~	~~x~~	~~x~~	~~x~~	~~x~~
Corominas et al. (2015)	x	x	x	x	x	x	x
Chandra and Grabis (2016)							

From Table 2 it can be observed that three papers address the SC design with a bottom-up approach, while the other two propose a top-down one. The use of activity graphs, initiated by Lakhal, Martel, and Oral (1999), combined with mathematical models and scenarios are the main tools considered for SC design (e.g. Lakhal et al. 2001; Vila, Martel, and Beauregard 2006; Corominas et al. 2015). All these works include the definition of the SC objectives, except Lakhal, Martel, and Oral (1999). Additionally, all them include explicitly the definition of elements for the SC structure (at the macro, meso and micro levels), except Chandra and Grabis (2016), which constitutes a general approach and does not detail which SC elements need to be defined. Only the framework of Corominas et al. (2015) incorporates the elements required for reverse logistics. Regarding the SC decisions, Lakhal et al. (2001), Vila, Martel, and Beauregard (2006) and Corominas et al. (2015) include a mathematical programming model to support the decision-making process.

4. Definition of the objectives of the SC

The definition of the objectives of the SC must be a primary step in the process of the SC design or redesign. Here, the meaning of 'objectives' is twofold. On the one hand, the word refers to the purpose of the SC. On the other hand, to the kind of goals (economic or others) to be reached by means of the SC operation: this is, the criteria for evaluating the behaviour of the system. Both aspects are basic to define rightly the characteristics of the SC.

A good definition of the purpose of the SC requires the specification of the package of goods and services to be produced and distributed. For instance, selling books is not a good definition of the purpose of the SC because this will be very different if the purpose is to sell books by means of a network of brick-and-mortar bookstores or through Internet: the product, i.e. the package of good (books) and services is quite different in both cases and so has to be the SC network; probably, the kind of books to be sold should also be specified.

Considering the acceptation of objectives as goals, it seems that many papers give for granted, without any discussion, a specific objective (e.g. the net present value) or a set of objectives to be optimised, in spite of this not being a trivial issue. From the point of view of the SC paradigm, identifying the goals is particularly complex, because of the multiplicity of partners that can deserve the consideration of stakeholders.

Economic issues are always present in one way or another, but in many SCs they are not the main objectives, but rather a constraint (for instance one objective of the SC of an ONG, with a given budget, may be to provide food and drinking water, as soon as possible, to the victims of a disaster). Moreover, even among the strictly economic criteria, one can found a variety of non-equivalent options. Minimise the costs or the present value of the costs, which is adopted as the main or even is the unique objective of the SC in many papers, is not a right option unless it is supposed that the incomes are fixed (however, this is not the case if to serve all the demand is not mandatory); Klibi, Martel, and Guitouni (2010) and Klibi and Martel (2012, 2013) argue that the design of the SC represents a more complex and heterogeneous problem than that of minimising costs, since this should maximise the value of the SC, the revenues for the company and the quality in the service level.

Therefore, maximise profits will be in many settings a better option. However, even when economic criteria prevail, other criteria must often be taken into account (for instance, lead-time, robustness or resilience). In this regarding, Melnyk, Narasimhan, and DeCampos (2014) point out that SCs can be designed to aim alternative outcomes, i.e. responsiveness, driving innovation or improving sustainability. A clear example of this variety in the SC goals is shown in Wilhite et al. (2014) where AQ4 the authors present a model for the military SC design where the main objective is not the economic one, but to achieve a particular state of readiness in the military industry.

On the other hand, sustainability has gained momentum as a comprehensive goal in the design and the operations of SCs (Zhu and He 2017). The design of a sustainable SC should consider, alongside the economic issues, the social responsibility and environmental ones (green; Ahi and Searcy 2013; Bhattacharya, Dey, and Ho 2015; Eskandarpour et al. 2015; Govindan, Fattahi, and Keyvanshokooh 2017). Altogether, they yield the so-called three dimensions of a sustainable SC (Mota et al. 2015).

~~However, s~~Studies that deal with the three dimensions are unusual. However, Chardine-Baumann and Botta-Genoulaz (2014) consider ~~the three dimensions mentioned~~all them: economic (financial performance), environmental (protection of natural environment, pollution) and social (working conditions, human rights).

Concerning social aspects, an analysis of the literature (Seuring and Müller 2008) revealed that they have received a relative scarce attention with respect to the economic and environmental sides of the SCD. Among the works considering them, Zhou, Cheng, and Hua (2000) include an ethical compromise while meeting the customers demand, Wittstruck and Teuteberg (2011) propose the social equity as a goal and in You et al. (2011) the specific social objective is to maximise the number of accrued local jobs. Pishvaee, Razmi, and Torabi (2012) consider the social aspect (including human rights, labor practices and communities' development) as a key element in the design of a sustainable SC. In the same line, Wu et al. (2017) consider as a main aspect for the design of the SC the corporate social responsibility (i.e. the social and environmental customers' interests). Altmann (2014) also considers customers' environmental requirements as one of the main aspects for the design of a sustainable SC.

For its part, greenness is a complex concept that includes different environmental concerns (Nikolopoulou and Ierapetritou 2012; consider energy consumption and waste minimisation, product recovery – in order to recycle and remanufacture – and water management). The awareness of the environmental repercussions is a result of corporations facing new realities and social necessities, and of the inclusion of new evaluation mechanisms for the fulfillment of their legal and social responsiveness (Chaabane, Ramudhin, and Paquet 2011). Kadziński et al. (2017) and Puji Nurjanni, Carvalho, and Costa (2017) remark the increasing importance of the environmentally consciousness in literature regarding the SCD. In studies such as Ashby, Leat, and Hudson-Smith (2012) and Nikolopoulou and Ierapetritou (2012) it is pointed out that green SC practices not only help with the increase of the energy efficiency and with the reduction of the negative environmental influences, but they also enhance economic performance and competitiveness among companies. Klassen (2001) and Zhu and He (2017) consider that the implementation of such practices can help the companies in the long-term sustainability.

Social equity and civil liability, ethical implications, carbon footprint and CO_2 emissions, and energy consumption are the most frequently considered, among the diverse sustainable criteria discussed in the literature on SCD.

As early as 1998 Beamon enumerates fifteen performance measures, which were classified into two groups, qualitative and quantitative, the latter divided into two subgroups (according to whether the measures were based on cost or on customer responsiveness). The same paper (Beamon 1998) presents a table with ten performance measures used in SC modelling. Since the publication of Beamon's article, other performance criteria have been presented in the literature. We summarise them, integrated in Beamon's scheme, in the Appendix 1 of the present paper. As can be noted there, the diversity in the design objectives have been increasing over the years. Among these new considerations, we can highlight those related with sustainable aspects such as environmental or social issues.

Hence, the objectives of a SC offer a great variety. Moreover, as one single measure cannot take account of all the relevant consequences of a given configuration, SC design is, in the vast majority of cases, a multicriteria problem, as Truong and Azadivar (2005), von Massow and Canbolat (2014), Scott et al. (2015) and Chandra and Grabis (2016), among many others, point out. An additional complication comes from the fact that in multicriteria settings some criteria can be dealt with as constraints to be fulfilled rather than objectives to be optimised.

All this notwithstanding, the literature offers scarce indications about the selection of criteria concerning SC design and about the way to combine them, either in a hierarchical way or establishing appropriate trade-offs or using a specific utility function. Scott et al. (2015), however, present a conceptual model that can be useful for defining evaluation criteria in order to compare alternative configurations of a SC; essentially, the approach consists of three phases: stakeholder identification and salience (Mitchell, Agle, and Wood 1997), incorporation of their opinions into the decision process, and decision making according to the criteria outlined by the stakeholder group.

5. The design of the reverse SC

Although the early SC definitions do not include the concept of reverse flows, these are nowadays recognised as an inseparable element of most SCs. However, John and Sridharan (2015) claim that 'few researchers have addressed the issue of development of a general framework for the [reverse] network design'. Even though, the literature includes general approaches to the design of the reverse SC (RSC) and definitions of specific relevant variables to be taken into account.

As the RSC is a part of the whole SC, it must be present from the very beginning of the process of designing the whole SC (as it is pointed out in SCOP method – Corominas et al. 2015 –, which includes considerations about collection and reprocessing options), in order to coordinate the decisions concerning the design of the product, the forward SC and the RSC (El-Korchi, Millet, and Colin 2009; Pishvaee, Farahani, and Dullaert 2009, 2011). Note that the joint design of the forward and the reverse SCs is even more necessary when all the reverse flow or a part of it becomes an input at some point of the forward SC (i.e. in a closed loop SC), because, then, the stochasticity inherent to RSC (concerning quantity, quality, time and place of recovering the used product) is transmitted to the forward chain.

On the other hand, the concepts of PRV (Product Residual Value) and MVT (~~, m~~Marginal ~~v~~Value of ~~t~~Time, ~~(~~the speed at which the used product losses value) are recognised by many authors as most relevant for RSC design.

MVT was introduced by Blackburn et al. (2004), who, recovering the terminology proposed by Fisher (1997), relate high and low values of MVT, respectively, to efficient and responsive RSCs. In a similar vein, Guide et al. (2006) stress that in the design of the RSC the maximisation of the recovered value must prevail over cost minimisation, introduce the concept of preponement and combine the time-value decay with the proportion of new returns to identifying the most suitable type of RSC. Huang and Liang (2011), use MVT as a key concept for RSC design and associate centralisation to efficient RSCs and decentralisation to responsive ones.

Gobbi (2011), instead, identifies PRV as the main driver of the RSC design: low PRV is associated with the so-called second-class recovery options (energy recovery and recycling), while high PRV is associated with reconditioning and remarketing (first-class recovery options). In order to link PRV with Fisher's typology, Gobbi relates low PRV with innovative products and high PRV with functional ones. However, despite the pre-eminence given to the PRV, the author also considers the MRV and analyses the implications of the various possible combinations of the values of both variables.

6. Financial aspects

Financial factors have a relevant impact on the configuration of most SCs. Since the implementation of a SC design or redesign often implies to invest large amounts of capital in new infrastructures or in the adjustments of the existing facilities, the financial restrictions condition the design of the SC. However, few papers take them into consideration.

With not many exceptions, it is usually assumed that all the investments are financed by equity. However, to cope with more realistic settings, a company should take into account, among other financial aspects, budget limitations (e.g. Fleischmann, Ferber, and Henrich 2006; Oh and Karimi 2004; and Melo, Nickel, and Saldanha-da-Gama 2005). Nevertheless, budgetary constraints are insufficient, because they do not allow balancing cash flows between the time periods of the SC planning horizon. Therefore, there is a need to consider different financial sources and instruments in the design of the SC, and to coordinate SCD and financial planning (Naraharisetti, Karimi, and Srinivasan 2008; Ramezani, Kimiagari, and Karimi 2014; Steinrücke and Albrecht 2016).

Financial aspects influence even the objectives of the SC, through the consideration of the stakeholders' interests (see Section 4). SC redesign may result from mergers and acquisitions (Harrison 2004) of well positioned companies, often by institutional investors. In this case, all relevant decisions related to SC configuration and operations are subordinated to the institutional investor's aims and its revenue expectations. In this context, Steinrücke and Albrecht (2016) propose to maximise the present value of equity whilst determining annual payouts to an institutional investor during its engagement.

Additionally, since the design of a SC envisages a time horizon of several years, the time value of money should be considered. Based on the financing of the SC, the cost of capital should be used to discount the cash flows and to calculate the present value. The discounted free cash flow method uses the weighted average cost of capital (WACC) for discounting, as a combination of returns needed to compensate creditors and shareholders. In contrast, within the flow-to-equity approach, the equity discounting factor should be used (e.g. Steinrücke and Albrecht 2016, determine the discounting rate according to the capital asset pricing model – CAPM – for the cost of equity capital of a levered company).

Other financial considerations, such as taxation, affect the design of global SC, since different countries have different corporate taxes, and this influences important design decisions such as the location of facilities and the amount to invest or disinvest in different geographic zones.

7. Generation and use of scenarios

The question of how to take into account the uncertainty does not appear only in the design process of the SC, but in any strategic planning process and in particular in the strategic planning of the capacity of any production and logistics system.

The abounding literature on the topic focuses on the application of fuzzy numbers (Chiu and Teng 2013; Jindal and Sangwan 2014; Saffar, Shakouri, and Razmi 2014 and 2015, Gholamian et al. 2015), and especially on considering a set of scenarios that often are incorporated into stochastic mathematical programs. The scenario approach leads usually to more tractable models that the use of continuous stochastic parameters, as is pointed out in Govindan, Fattahi, and Keyvanshokooh (2017), where other references related to scenario generation can be found.

Uncertainty can be associated to the evolution of the economic context (exchange rates, taxation, GDP growth), the legal frame (various regulations, such as those relating to the environment), demography, demand, costs or technological developments, among others. To this respect, the design of the SC presents no qualitative difference with the problems of strategic planning capacity, but in global SCs the more or less interdependent sources of uncertainty outnumber those that are usual in traditional production and distribution systems. Hence, the scenarios to be considered are in principle much more numerous (about grouping scenarios: Crainic, Hewitt, and Rei 2014; on the resolution of models with a huge number of scenarios: Santoso et al. 2005).

The fact of applying mathematical programming in uncertain contexts does not imply the use of stochastic programming. Mansoornejad, Pistikopoulos, and Stuart (2013), state that a biorefinery strategy depends on many factors (such market strategies and emerging products and technologies, among others) that are difficult to address within a single optimisation model. Consequently, they propose to use optimisation models to evaluate each network alternative in diverse market scenarios. For each alternative/scenario pair the optimal profit and the corresponding flexibility and robustness metrics are calculated. The decision-maker adopts the final solution in view of the solutions provided by the models and their respective calculated metrics.

Likewise, Charles et al. (2016), referring to humanitarian supply networks, come to the conclusion, according to Shapiro (2000), that building multiple scenarios and optimise a MILP model for each scenario is better than a stochastic or robust approach.

Three related papers (Klibi, Martel, and Guitouni 2010; Klibi and Martel 2012, 2013) introduce new conceptual elements relative to the design of robust value-creation SCs. The aim of the first of these three papers (Klibi, Martel, and Guitouni 2010) is to contribute to framing a robust SC design methodology. The authors enumerate the vulnerability sources of a SC, which they classify into three main groups (endogenous assets, SC partners and exogenous geographical factors) and, additionally to the traditional distinction between certainty and uncertainty, consider, in the common frame of uncertainty, randomness (random variables associated to the usual activities are known), hazard (corresponding to low-probability events having a potential high-impact) and deep uncertainty (when lacks any information concerning the likelihood of future plausible extreme events). This categorisation is related to the distinction between recurrent or operational risks and disruptive risks (Torabi et al. 2016; Ivanov et al. 2017; see also Inman and Blumenfeld 2014; for the relation between product complexity and risk of disruption). Based on the aforementioned concepts, Klibi and Martel (2012) detail how to generate plausible future scenarios and Klibi and Martel (2013) deal with the consideration of the generated scenarios into a stochastic mathematical programming framework.

From the point of view of the present paper, the most relevant of the three previously mentioned articles is Klibi and Martel (2012), where the authors propose a partition of the set of future scenarios into two subsets. All probabilistic scenarios (i.e. without deeply uncertain events) belong to one of these subsets and all the remaining, to the other one. According to the authors, the three fundamental questions relative to risk analysis concerns what can go wrong, what are the consequences and the likelihood of that coming about is. However, only the two first questions may have an answer for deep uncertain events. The SC network hazard modelling approach that is proposed consists of three phases, whose developments, which may be very complex, are described in detail in the paper:

- •characterisation of multihazards and vulnerability sources
- •modelling of multihazard processes
- •modelling the impact of hits on the SC network.

8. Conclusions and future lines of research

Based on the analysis of the revised literature, we have reached the conclusions contained in subsection 8.1, partially suggested above, from which we have derived the proposals for future lines of research that are contained in subsection 8.2.

On the other hand, we think that an effort has to be made from academia in order to ‘packaging’ the research contributions to SC design so they be usable by organisations, as it is said in Kouvelis, Chambers, and Wang (2006): ‘SCM researchers still need to do a better job of packaging the insights derived from SCM research for SCM professionals’. In our opinion, it is necessary to elaborate handbooks that collect and develop in a coherent framework the pertinent academic contributions to make them affordable to practitioners.

8.1 Conclusions

- •The guide provided by a method and the help given by the associated tools are particularly necessary in the design of a SC, because it is a process with higher complexity that the design of a traditional production and logistics system. Yet, the analysis of the literature reveals that, although valuable generic frameworks and methodological elements can be found, the methodological contributions to the design of the SC are not abundant and, finally, insufficient for practitioners having to deal with this kind of problem.
- •The use of mathematical programming models for mapping the set of activities on the set of resources is generally convenient, if not indispensable. However, contrary to what a part of the literature seems to suggest, the process of designing a SC should not be identified with the formulation and resolution of a mathematical programming model.
- •The approaches based on a typology are not a sufficient guide for the design of the SC.On the one hand, because there is not a consensus on terms and concepts, what is clearly inconvenient from the point of view both of academics and practitioners.On the other hand, because, although they involve useful ideas for designing and managing SCs, the typologies are insufficient for one thing and the other. To identify the most convenient type of SC for a given product is not enough to provide an adequate support to all the decisions involved in the design of the SC.Moreover, the product typologies proposed by some authors are not exhaustive, this is, they do not embrace all possible types of products, even in relation to the considered characteristics.The proposal of hybrid types has been an attempt to overcome the inadequacies of the pioneer pure types. However, the idea of separating the SC into two parts, one lean and another agile, is interesting and may be valid enough in some circumstances. ~~However~~Yet, in general is too rigid, because, even if we confine ourselves to the binary classification lean vs. agile, the possibility of choosing one or the other out of these options exists for each module or component of the product and, in general, for each component of the SC network.Even though the concept of decoupling point is very relevant for achieving short delivery lead-times, it has a lower incidence or even is irrelevant with respect to other attributes of agility. To determine the position of the decoupling point is a very important decision in the design of the SC, but does not define its configuration.
- •The methodologies based on a succession of stages may constitute an appropriate approach for SCD. However, they are scarce and, at least considering their descriptions in the literature, not developed enough to serve as a sufficiently effective guide to practitioners (for instance, SCOP would require a deepening relative to the decisions corresponding to the design of the production process, among others).The eight steps proposal of Chandra and Grabis (2016) constitute a general frame that even can be applied to design problems different from that of configuring the SC.We think that top-down approach is more adequate than bottom-up, because the latter requires a great effort to carry out the collection and analysis of information, some of which turns out to be unnecessary during the design process, because it corresponds to high level options that are discarded without resorting to the detailed information provided.
- •Generally, services, even those required for managing the SC, appear marginally in most methodological proposals.
- •Because of its environmental and economic implications, reverse logistics, including closed loop SCs, deserves full consideration from the very beginning of the SCD process.

- •The identification of criteria for evaluating alternative proposals to configure a SC is particularly complex because of the presence of a multiplicity of stakeholders of different relevance. The fact that this question is not even mentioned in a significant part of the literature may give the impression that it may be answered trivially.
- •Sustainability is being increasingly taken into account in the design of the SC. However, despite recent approaches, the three dimensions of sustainability are not generally addressed and literature concerning sustainable design concentrates on the environmental dimension, leaving aside the social one.
- •The determination of the length of the planning horizon is an important issue that has deserved scarce attention. In spite of being mentioned in Vila, Martel, and Beauregard (2006) and in Corominas et al. (2015) as one of the first decisions to be made in the design process, we have not found papers dealing with how to define it and establish, consequently, the desired state of the SC at the end of the horizon.
- •The literature does not reflect the crucial role of financial aspects in the configuration of the SC. At least, budgetary constraints, diverse sources of funding, and taxes, should be in the diverse SC envisaged scenarios.
- •Concerning generation and use of scenarios in SCD, the classifications in Klibi, Martel, and Guitouni (2010) and Klibi and Martel (2012) constitute a good starting point and provide a general frame for this kind of research.
- •From a theoretical point of view, the distinction between design and redesign is not very important. However, in practice is relevant because, in the case of redesign, sufficient information about the current configuration of the system is required, since it has obviously to be taken into account when elaborating the proposal of reconfiguration.However, there is little emphasis in the literature on this distinction (for example, the first step in the method proposed in Chandra and Grabis 2016, is ‘updating the SC strategy’, but they do not develop this point thereafter), if it happens to mention it at all.
- •The redesig~~ning~~ of SCs is related to another question, much less treated in the literature but that often occurs in practice, namely, the reconfiguration of an existing SC when a new element is to be incorporated into the product portfolio. This, in turn, is related to an issue even more general that has not been developed either, this is, integrating the SCs corresponding to different products (note that in Lakhal, Martel, and Oral 1999, each product has an associated product-market chain and the authors refer to the situation where there is a multiplicity of industrial products as an *industrial trellis* giving some indications on how to deal with it).

8.2 Future lines of research

The main derivation of the preceding conclusions for the prospects of research is that there is a need of developing holistic approaches to the design of supply chains, including their components relative to reverse flows. Such approaches may concern all kinds of SCs or the SCs corresponding to specific activity sectors, especially services.

In both cases, we advocate frames based on a succession of stages, with a top-down approach.

In the process of building such holistic frames, particular attention should be given to the following issues:

- •Establishment of an agreed, well-defined terminology.
- •Development of tools to formulate and solve mathematical programming models for mapping the set of activities on the set of resources.
- •Elaboration of sets of options for the different types of activities that take place in the SC, including in particular those corresponding to reverse logistics.
- •Identification of stakeholders and their preferences.
- •Definition of criteria in order to take into account the economic, environmental and social dimensions of sustainability.
- •Definition of the duration of the planning horizon.
- •Integration of the financial aspects in the design of the SC.
- •Analysis of sources of vulnerability for each activity sector, as did Vlajic, van der Vorst, and Haijema (2012) for food SCs.
- • Generation and use of scenarios.
- •Redesign of the SC and integration of the SCs of different products.

Summing up, although valuable generic frameworks and methodological elements can be found in the literature, our analysis reveals that there is many room for research, along diverse lines, on holistic, detailed methodologies and tools to drive the decision-making process of designing the SC.

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Appendix 1. Objectives in the design of supply chain

Design objectives	Period				
	From 1981 to	From 1989 to	From 1996 to	From 2004 to	From 2011 to

	1988	1995	2003	2010	2017
Cost					
• •Min. Cost • •Min. Average inventory levels • •Max. profit • •Max. buyer-supplier benefit • •Max. the profit for stakeholders • •Max. the revenues	Williams (1981), Williams (1983) Cohen and Lee (1988) Ishii, Takahashi, and Muramatsu (~~1998~~ 1988) AQ6	Cohen and Lee (1989) Cohen and Moon (1990) Svoronos and Zipkin (1991) Lee, Billington, and Carter (1993) Pyke and Cohen (1993), Pyke and Cohen (1994) Christy and Grout (1994) Towill and Del Vecchio (1994) Tzafestas and Kapsiotis (1994) Altiok and Ranjan (1995) Lee and Feitzinger (1995)	Camm et al. (1997) Kouvelis and Yu (1997) Lee, Padmanabhan, and Whang (1997) Beamon (1998) Zhou, Cheng, and Hua (2000) Klassen (2001)	Lee (2004) Dotoli et al. (2005) Truong and Azadivar (2005) Martínez-Olvera and Shunk (2006) Vila, Martel, and Beauregard (2006) Klibi, Martel, and Guitouni (2010)	Chaabane, Ramudhin, and Paquet (2011) Wittstruck and Teuteberg (2011) You et al. (2011) Klibi and Martel (2012) Pishvaee, Razmi, and Torabi (2012) Ahi and Searcy (2013) Klibi and Martel (2013) Hilletofth (2012) Chiu and Teng (2013) Wilhite et al. (2013) Altmann (2014) Chardine-Baumann and Botta-Genoulaz (2014)

					von Massow and Canbolat (2014)
					Chiu and Okudan (2014)
					Melnyk, Narasimhan, and DeCampos (2014)
					Bhattacharya, Dey, and Ho (2015)
					Corominas et al. (2015)
					Eskandarpour et al. (2015)
					Mota et al. (2015)
					Govindan, Fattahi, and Keyvanshokooh (2017)
					Kadziński et al. (2017)
					Nurjanni, Carvalho, and Costa (2017)
					Wu et al. (2017)
					Zhu and He (2017)

Customer					
• •Min. the activity days and total cost • •Achieve target service level (fill rate) • •Customer satisfaction • •Min. the variance of the demand • •Delivery time • •Min. of the response time		Towill (1991) Wikner, Towill, and Naim (1991) Towill, Naim, and Wikner (1992) Lee, Billington, and Carter (1993) Lee and Billington (1993) Newhart, Stott, and Vasko (1993) Towill and Del Vecchio (1994) Arntzen et al. (1995)	Beamon (1998)	Martínez-Olvera and Shunk (2006) Klibi, Martel, and Guitouni (2010)	Klibi and Martel (2012) Pishvaee, Razmi, and Torabi (2012) Klibi and Martel (2013) Altmann (2014) Chardine-Baumann and Botta-Genoulaz (2014) Corominas et al. (2015)
Product					
• •Max. the value of the product • •Value generation				Lee (2004) Zolghdri *et al.* (2008) Klibi, Martel, and	Klibi and Martel (2012) Klibi and Martel (2013) Hilletofth (2012)

				Guitouni (2010)	Chardine-Baumann and Botta-Genoulaz (2014) Corominas et al. (2015) Scott et al. (2015)
Stock and capacity • •Min. stock-out probability • •Max. available system capacity • •Innovation capacity of stakeholders • •Lead time	Ishii, Takahashi, and Muramatsu (1998)	Altiok and Ranjan (1995)	Voudouris (1996) Beamon (1998)	Truong and Azadivar (2005)	Chiu and Teng (2013) Chiu and Okudan (2014) Melnyk, Narasimhan, and DeCampos (2014)
Sustainable aspects Environmental • •Carbon footprint • •Min. the CO_2 emissions • •Energy consumptions • •Energy waste Social • •Civil liability • •Social equity • •Ethical implications			Zhou, Cheng, and Hua (2000) Klassen (2001)	Dotoli et al. (2005) Seuring and Müller (2008)	Chaabane, Ramudhin, and Paquet (2011) Wittstruck and Teuteberg (2011) You et al. (2011) Ashby, Leat, and Hudson-Smith (2012) Klibi and Martel (2012)

					Nikolopoulou and Ierapetritou (2012)
					Pishvaee, Razmi, and Torabi (2012)
					Ahi and Searcy (2013)
					Klibi and Martel (2013)
					Chiu and Teng (2013)
					Altmann (2014)
					Chardine-Baumann and Botta-Genoulaz (2014)
					Melnyk, Narasimhan, and DeCampos (2014)
					Bhattacharya, Dey, and Ho (2015)
					Eskandarpour et al. (2015)
					Mota et al. (2015)
					Scott et al. (2015)

					Govindan, Fattahi, and Keyvanshokooh (2017) Kadziński et al. (2017) Nurjanni, Carvalho, and Costa (2017) Wu et al. (2017) Zhu and He (2017)
Other objectives • •Capacity of managing risks • •Competitiveness • •Efficiency • •Agility • •Resilience • •Max. the flexibility • •Reliability • •Responsiveness • •Robustness		Eppen, ~~Kipp~~ Martin, and Schrage (1989)	Kouvelis and Yu (1997) Beamon (1998) Dornier et al. (1998) Vidal and Goetschalckx (2000) Bertrand (2003) Graves and Willems (2003)	Lee (2004) Dotoli et al. (2005) Sheffi (2005) Snyder and Daskin (2005) Wang, Huang, and Dismukes (2005) Dong (2006) Martínez-Olvera and	Hilletofth (2012) Klibi and Martel (2012) Klibi and Martel (2013) Wilhite et al. (2013) Chardine-Baumann and Botta-Genoulaz (2014) Melnyk, Narasimhan, and DeCampos (2014)

				Shunk (2006)	von Massow and Canbolat (2014)
				Snyder and Daskin (2006)	Corominas et al. (2015)
				Vila, Martel, and Beauregard (2006)	Govindan, Fattahi, and Keyvanshokooh (2017)
				Berman, Krass, and Menezes (2007)	Wu et al. (2017)