Investing in Supply Chain Flexibility: A Design Framework

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***Abstract*— The aim of this paper is to contribute to the managerial knowledge development about supply chain capabilities. In the years to come, supply chains (SC) need not only to excel on cost and time, but also improve further in terms of flexibility. Our main contribution is a conceptual design framework that guides managers when investing in flexibility. First, we define a set of flexibility objectives, which differentiates between short- vs. long-term flexibility, and product vs. process flexibility. Second, the framework provides design constructs differentiating three design levels: single resource, single stage, and multi-stage SC.**

***Index Terms*—supply chain management, flexibility, design framework**

I. Introduction

The primary goal of supply chain management (SCM) is to efficiently match demand with supply. During the last years, many companies have invested in new supply chain (SC) technologies, hired talent, or outsourced activities in order to improve the performance of their SC. Most initiatives, however, were targeted chiefly at delivering goods and services to customers with less costs and faster, traditionally the two most popular concerns in SCM.

The focus on cost optimization resulted in a majority of the SC being designed and built to manage rather stable, high-volume flows. However, they seem not to be equipped optimally to cope with the business challenges that they need to face in the coming years, as for example, demand volatility, customization, regulatory uncertainty, or disruption risks. These are actually not really new issues to SCM, but definitely have become more acute than before, not at least given the developing world's increase in raw material and final products consumptions, or the tighter regulations in exports and imports for key products [1].

To overcome this thread, successful companies have gradually evolved their SC giving a much higher priority to flexibility and responsiveness [2]. As a result, these new SC are becoming a source of competitive advantage for the companies. But this has an inherent trade-off, as increasing flexibility usually comes with costs associated to it, so a careful design is paramount.

Also in the academic literature flexibility has been a mayor research topic [3]. Researchers have proposed different perspectives of flexibility, and several models to analyze and improve it. However, no unified definition or framework exists to guide managers in their efforts (to our knowledge).

In this paper we aim to trace a bridge between industrial practice and academic research by addressing the following three main research questions:

1. Why should companies develop more flexible and responsive SC in the years ahead both on the demand and the supply side?
2. How can flexibility and responsiveness be made more specific objective?
3. What design constructs and principles can be identified from academic literature to can help SC managers designing SC that perform better in terms of flexibility and responsiveness?

The structure of this paper is as follows. In the next section we first analyze the new challenges SCM will be facing going forward, as well as its implications for future SCM models. Based on a literature review, we then analyze definitions of the constructs of flexibility, responsiveness, and alike. In a fourth section we integrate the findings into a conceptual framework that aims to help SC managers when upgrading their SC in terms of flexibility. Finally, we summarize our contributions and its implications for future research and practice.

II. SCM Challenges Ahead

An increase in market competition can have different characteristics in practice, but generally leads to phenomena as pressure on prices and promotions, higher product customization, shorter product life cycles, and demand volatility [4]. Costs will therefore remain an important SC objective in the years to come, but companies need to balance this with the need for flexibility and responsiveness resulting from an increase of demand uncertainty, requests for customization and customer service, or technological advancements. Examples like Toyota’s recall of millions of vehicles due to product issues, Apple's stock outs of new iPhones, or the recent impacts of the Tsunami have illustrated how important this can be. Additionally, higher levels of uncertainty in commodity prices, exchange rates, and governmental regulations are faced.

When putting all these challenges together it becomes clear why companies are challenged in their ability to manage their SC successfully. Moreover, to succeed

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along all open SC battle-fronts is not really possible as they may be in conflict. Typical strategies as to move production from one low-cost country to the next cheaper one, further away from their main demands, for example, or increase dependence on price discounts, have proven to make customer service harder and to amplify even more the exposure to context factors as regulation, exchange rates, etc.

Table I summarizes some of the main challenges companies will face in the years to come, and lists examples of some mayor implications these challenges have for SCM.

TABLE I. SUMMARY OF KEY FUTURE SCM CHALLENGES

Challenge	Examples of Key Implications for SCM
Higher product and components complexity	• More complex inventory management • Higher interdependency of production and sourcing • Higher disruption risk • Increased burden on monitoring quality and service levels
More customization and product (offering) variety	• Higher demand variability • Smaller quantities per SKU • Shorter product life-cycles • Higher service levels beyond product specifications
More pressure on prices and discounts	• Higher demand variability • Higher efficiency requirements
Increased demand uncertainty	• Risk of stock-out as well as overstock • Better forecast or responsiveness required
Labor costs increase in developing countries	• SC configurations need to evolve over time along with labor costs • More global operations in unexploited countries • Monitoring of quality and service levels
Specialization and global competition of suppliers	• Higher disruption risk • Higher dependency on fewer companies in an industry • Higher exposure to trade barriers and international regulations
Increasing commodity and x-rate volatility	• Supply and cost variability • SC need to accommodate changing flows over the short term to leverage cost • Hedging and responsiveness
Increased regulations on trade and product responsibility	• Higher disruption risk • Higher transaction costs and risk of law suits • Higher uncertainty in lead times due to customs

III. LITERATURE REVIEW: DEFINITIONS OF RESPONSIVENESS, FLEXIBILITY, AND BEYOND

The debate about what flexibility, responsiveness, and similar adjectives of SC means, and how it can be achieved has been going on for a long time both in industrial practice as well as academic literature [5]. Over the years, in the practitioner arena, many successful SCM initiatives have been developed by consumer goods companies. Well known and documented are, for example, initiatives as quick response (originally started in apparel), efficient consumer response (from FMCG), or collaborative planning, forecasting and replenishment (food retailing), as well as modularization of products, manufacturing platforms, or outsourcing [6]; [1]; [2].

In the academic arena, several authors have studied how to define flexibility for an operations system and how it can be achieved. It can be argued that the concepts of flexibility, responsiveness and alike were already in the focus of the General System Theory and Cybernetics [7]. [8] raised already two decades ago the challenge: "flexibility is a complex, multidimensional, and hard-to-capture concept". A decade later [3] confirmed that there was no clear and unified definition of flexibility in the literature. [5] performed a next mayor review of the evolution of these concepts in literature, and proposed further additions to the understanding of flexibility.

We undertook a comprehensive literature review to identify key and representative definitions and models. We began by searching for articles on the following key words: flexibility, responsiveness, agility, and adaptability of manufacturing systems or supply chains. We did search for the period of 1990-2013 within a selection of highest impact journals from operations management and related disciplines. The key findings are summarized in Table II.

This analysis was complemented by keyword searches on these key words using the online resources ISI Web of Science® and Google ScholarTM. These searches were focused to identify journal articles only from operations and supply chain management, as there exists also literature from other academic disciplines. Moreover, only papers specifically concerned with definitions, antecedents, and consequences of flexibility in operations and SC were considered for further investigation.

TABLE II. SUMMARIZES REPRESENTATIVE DEFINITIONS OF FLEXIBILITY, RESPONSIVENESS AND ALIKE.

Authors	Definition
[9] Olhager (1993)	In the short run, flexibility means the ability to adapt to changing conditions using the existing set and amount of resources. In the long run, it measures the ability to introduce new products, new resources and production methods, and to integrate these into the existing production system.
[10] Watts et al. (1993)	Flexibility is the ability to implement changes in the internal operating environment in a timely manner at a reasonable cost in response to changes in market conditions.
[11] Upton (1994)	Flexibility is the ability to change or react with few penalties in time, effort, cost, or performance.
[12] Kritchanchai and MacCarthy (1999)	"Responsiveness is the ability to react purposefully and within an appropriate time-scale to customer demand or challenges in the marketplace, to bring about and maintain competitive advantage."
[3] D'Souza, and Williams (2000)	Identified four dimensions of manufacturing flexibility: volume flexibility, variety flexibility, process flexibility, and materials handling flexibility. Each dimension has two elements: range and mobility. Range defines the extent of flexibility on each dimension. Mobility represents the firm's agility in making the changes on each dimension.
[13] Vokurka, and O'Leary-Kelly (2000)	Introduce a contingency framework on interrelationships of manufacturing flexibility. The framework identifies four exogenous variables (strategy, organizational structure, environmental uncertainty, and technology) that moderate the relationship between manufacturing flexibility and performance.
[14] Graves and Tomlin (2003)	Process flexibility is the ability of a production facility to produce multiple products. It can be measured by a flexibility measure g, which is a

	function of M (set of products) and the excess capacity available. This measure allows to analyze which flexibility structure is most efficient provided all stages of the supply chain make use of the same flexibility structure.
[15] Lee (2004)	Differentiates between agility, adaptability and alignment. Agility is the capability to respond to short-term changes in demand or supply quickly and to handle disruptions smoothly. Adaptability is the capability to adjust the SC design to meet structural shifts in markets, modify supply networks to strategies, products, and technologies.
[5] Holweg (2005)	"Flexibility is a generic ability to adapt to internal and/or external influences". "Responsiveness is the ability to respond to customer requests in the marketplace. To achieve it, certain types of flexibility are required of the manufacturing system itself, as well as of the supply and logistics subsystems. The types of flexibility required to achieve such responsiveness in the supply chain are contingent upon the system's structure and environment."
[16] Iravani et al. (2005)	They introduce the construct of structural flexibility as a system's capability, provided by its structure of multicapability sources, to reallocate production to respond to changes in demand (e.g., volume, work content, product mix, etc.) or in source capacity (e.g., absenteeism, breakdowns, rework, etc.).
[17] Hopp et al. (2010)	The flexibility within a stage of multiechelon SC is the horizontal flexibility. Vertical flexibility is about which stage the SC has flexibility. A certain SC structure has then two types of flexibility: logistics flexibility is the ability to ship products to different locations, and process flexibility is the ability to produce different types of products.

We can summarize the literature review with some interesting conclusions. There exists no unified definition of flexibility, but researchers have learnt a lot about it - in fact we see that there are some recurrent ideas and concepts. First, we can conclude that flexibility can be considered a high level objective that an organization may pursue. To improve towards this objective requires the development of certain organizational capabilities. Concepts that appear recurrently are flexibility in terms of products and processes, but also the debate about the temporal horizon of the capability to be deployed. In the next section we try to integrate these ideas into a conceptual framework.

IV. A Design Framework

In this paper we aim at providing managers guidance as to how to improve the flexibility of their SC. To this extent, the first thing we propose is a more detailed specification of flexibility as an organizational objective, and to differentiate this conceptually from the actions an organization can undertake to improve in flexibility.

A. Flexibility Objectives

Following previous definitions found in literature, we propose the set of flexibility objectives summarized in Table III. It is a 2X2 classification that differentiates between a temporal (horizon) and an object dimension. Within the time perspective we differentiate between short- and long-term flexibility. With respect to the object dimension, the product dimension, on the one hand, reflects the capability to produce different product types and specifications (short-term agility), as well as the capability to develop new products in the future (long-term adaptability). On the other hand, there is the process dimension. In the short-term it is the capability to satisfy different demand requirements of a given product, for example, changes in volume or requested delivery dates. In the long-term it is the capability to adjust production processes to these needs, for example, through capacity investments, or new logistics partners or suppliers.

When an organization improves in terms of these flexibility objectives, we can argue based on the literature review that it improves implicitly as well in terms of flexibility as an organizational capability. We therefore define:

"*Flexibility is an organizational objective, which in the* particular *case of SC demands from the organization the capability of processing successfully a given demand over time in the face of certain context constraints. To improve towards this objective, the SC organization can undertake actions on itself in terms of human, technical, and organizational factors.*"

TABLE III. Set of Flexibility Objectives for a SC

	Object dimension	
Temporal dimension	*Products*:	*Processes*
Agility: this is the capability to respond quickly to sudden changes in demand or supply, and/or any other type of requirement or disruption to a SC	Ability to serve the product/service variety required • Need of variety and customization of products • Complex products offerings	Ability to produce and deliver products as they are required in the short term, i.e., • Adapt to demand volume changes (seasonality, disruptions, fashion trends) • Deliver with short lead times • Guarantee consistency and quality on production and delivery • React fast to supply disruptions
Adaptability: this is the capability to adjust the SC to longer-term changes and requirements; being it structural shifts in the markets, products, or technologies, for example.	Ability to adapt to changing context requirements • Develop/launch new products in a short life cycle context • Adapt quickly to new emerging markets or service requirements areas	Ability to adapt to changing supply and context requirements • Adapt volumes, source of capacity and supply as global economics (cost of labor) and financial (x-rates) politics change (trade barriers)

B. *Design Levels*

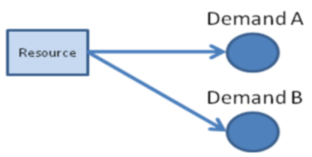
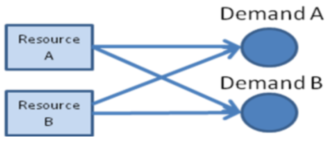
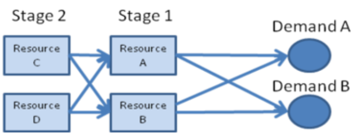
We propose managers approach flexibility improvements differentiating conceptually three structural levels. To start with, any operations system can be analyzed from a single system (resource) perspective, be it an operator, a machine, a factory or an entire SC, for example. On a second level, one can adopt a single SC stage perspective. Such a SC stage can be constituted by several resources. Here the concept of horizontal flexibility is useful [16]. Flexibility can then be represented by a bi-partite graph showing the relations between demand and supply sources. Relevant for the agility (short-term) at the SC stage is what the structure of the graph is. [18] developed guidelines for flexibility investments in such a single stage system. For example, they proved that chaining, ie. when all products (demands) and sources are (completely) connected in one closed chain, performs almost as well as total flexibility (all connected sources connected with all demands), but reduces required investments comparatively. Demand pooling is another typical instantiation of such types of flexibility. In terms of adaptability, this would represent the capability of adjusting such chain structures over time, be it with warehouse integrations or new supplier agreements, for example.

But a multi-echelon SC also presents the question of flexibility along the different SC stages of its structure. Here the concept of vertical flexibility [17] becomes of interest. In their paper they conclude, for example, that flexibility results generally most effective when positioned directly at the source of variability. So for example, if variability is originated by demand, it would be better to invest in agility downstream, while if originated by supply the opposite would be preferred.

Summing up, when a manager has to decide on how to improve flexibility of a SC, he can approach the investment decisions as follows:

1. First he should establish his coordinates within the set of objectives. Here priorities and equilibriums have to be defined on both the temporal perspective: agility (short-term) vs. adaptability (long-term), as well as the object axis (product vs the process dimension).
2. Then he can approach design on the three different structure levels: single resource, single SC stage, or along all SC stages

TABLE IV. SUMMARIZES DESIGN CONSTRUCTS OF AGILITY AND ADAPTABILITY

Level Note: Link implies that a product can be processed by resource	**Agility**	**Adaptability**
Single resource perspective  *Operational unit flexibility* Focus on single resource characteristics (i.e., traditional focus of process design and operations management)	***Product (Range flexibility)*** • Set-up/changeover management • Batching levels ***Process (Volume/Speed flexibility)*** • Resource capacity utilization levels • Inventories levels • Lead time management (manufacturing and transportation)	***Product (Design to market)*** • Ramp-up process mgmt • Industrialization process ***Process (Process adaptability)*** • Process layout design (cells, assembly line) ***Both*** • Multidisciplinary workforce training • Kaizen type production system
Single SC stage perspective  *Horizontal flexibility* (i.e., designing a graph structure that balances effectiveness and cost of flexibility). We can combine the previous design level with the option to achieve flexibility in different units at the same stage of the chain (i.e., focus on capacity strategic management)	***Product (Product commonality)*** • Modularity of products • Shared platform facilities • Component standardization ***Process (Volume commonality)*** • Centralization /decentralization/ chaining of capacity (pooling) • Centralization of inventory (pooling)	***Product*** • Modularity of products • Platform-based/shared design • Component standardization ***Process*** • Capacity hedging (real options)
Multiechelon SC perspective  ***Vertical flexibility*** (e.g., deciding at which SC stage flexibility is most effective.) We can combine the levers of the two previous levels with the redesign of the SC structure.	***Product and process*** • Push-pull decision • Buffer inventory location (decoupling point) • Information management • Collaborative supplier agreements (ECR, CPFR, VMI)	***Product and process*** • Product architecture decisions • Value chain design (Make/buy Outsourcing decision on production and R&D)

Such as decomposition allows, as we will illustrate in the next section, rationalize flexibility decisions and therefore optimize them. It also highlights the importance of thinking both short and longer-term. In Table IV we have summarized and illustrated the design constructs of our conceptual framework.

These three levels in fact have a recursive nature, as also a multiechelon SC can be viewed again as a single resource. However, we would argue that a manager should approach flexibility investments top-down, starting with decisions on the vertical flexibility (among SC echelons) and the subsequently move down to the improvement of specific stages and single resources.

V. Conclusions

In the face of current and future SCM requirements, flexibility in the broader sense has become a necessity for the competitive sustainability of companies. Several seminal contribution have been made to the understanding of flexibility, responsiveness and alike. In this paper we have proposed a definition of flexibility in the context of SCM as well as a conceptual framework intended to guide improvements in SC flexibility in industrial practice. It is primarily the result of the integration of the conclusions derived from our literature review and we want to highlight the following aspects of our framework.

First, the framework incorporates a set of objectives that are specific instances for the SC context of the general flexibility construct. We have proposed to separate conceptually these objectives from the actions (levers) that can be developed to improve a SC in terms of flexibility. Second, we argue that flexibility investments can be articulated at different, recursive design levels of a SC.

Finally, we want to stress that the framework presented here aims not to provide detailed normative design guidance. Rather, it is intended to support analysis of the design space and reflection on design decisions when trying to improve a SC. In order to make the framework more operational to practitioners, the aim of further research is to integrate it into a design methodology. To do so, further case studies will examine, among other things, the methodological principles to be made explicit in instructions for facilitating the use. These further practical validations should also help to identify opportunities for further details and improvement of the concepts.

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