A Theoretical Framework Assessment Proposal for a Complexity Degree Measurement on a Supply Chain Network

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Abstract. A complex system is usually defined as an environment that the current processes and activities do not allow a simple approach to the overall management tasks. Despite the distinct types of complexity present on a supply chain (SC), the management level needs a more comprehensive understating of how does it impact the SC performance, identifying the supply chain complexity (SCC) degree and applying the appropriate approach to support the decision-making and business risk assessment. Based on an exploratory research methodology, a theoretical framework proposal was developed and applied in a test case to validate potential use in the SC management network based on a literature review of the most recent works on SCC models. The preliminary findings were promising, and it is encouraging further investigation and model improvements.

Keywords: Supply chain · Complexity · Framework

1 Introduction

A complex system is usually defined as an environment that the current processes and activities do not allow a simple approach on the overall management tasks. Nowadays, the terminology "complexity" encompasses a new group of topics (information theory, chaos theory, system theory, cybernetic and risk management) that extends the concept to be understood as supply chain complexity (SCC) [1]. Were not found unified concepts of SC as complex systems, however, several definitions of complexity can be found. The first category is the structural complexity, in which there are several elements in a system and multiple interconnections within these elements. The second category is related to the functional complexity, composed by the dynamic resultant from the interrelation movement among these elements. The third category of complexity corresponds to modeling complexity. It is noteworthy that can occur problems resulting from the calculation of knowledge and the goals of conflict, due to the difficulty of standardization, and that these problems are closely related [2].

Blecker, Kersten and Meyer define supply chain complexity as the framework that combines volume and type of interrelated transactions, activities and processes across

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the supply chain (SC), integrating restrictions and uncertainties in accordance to these processes, transactions and activities take place [1].

Many approaches to measure the SCC could be found in the literature, e.g., information theory, non-linear dynamics, axiomatic theory, and specialist's panel, among others [3]. Although the identification of the complexity attributes on a SC is essential on a decision-making process, the current business environment requires to measure it related to costs and operational performance indicators, in order to identify improvement and needed mitigations actions [4]. Despite of the distinct types of complexity present in a SC, the management level needs a more comprehensive understanding how does it impact the SC performance, identifying the SCC degree and apply the appropriate approach to support the decision-making and business risk assessment [5].

These issues motivated several publications, presenting models that aim to identify the type of complexity, complexity drivers, logistical complexity, cognitive decision-making and risk assessment in the SCC environment. Extending the findings of Manuj and Sahin [6], that presents the SC and SC decision-making complexity model, the research question (RQ) that drives this work is:

> How to measure, in a pragmatic way, the degree of complexity on a SC network, considering the business environment inputs (internal and external to the SC), evaluating the relevant business dimensions (finance, customer perception, operational performance, process development and risks) to set the right actions to deal with the SCC?

The study presented in this paper is the first step, that aims to answer the RQ based on a theoretical framework assessment model proposal, limited on the qualitative inputs, and its application analyzed using trough a real test case to assess the approach potential.

The work from Manuj and Sahin [6], approaching the SCC model, was reviewed. The main contribution of the study of these authors was to follow the analysis of the variables do BSC extended to model [6], proposing a new scheme for measuring complexity through an inter-relationship between these two models, creating a basis for future researches. Within the following phase, the theoretical model will be required to be validated on a mathematical basis, case studies, application and simulation.

The paper content is structured as following: Sect. 2 presents the literature review background; Sect. 3 shows the methodology approach applied; Sect. 4 presents the theoretical assessment framework proposal; Sect. 5 shows the test case and the preliminary results; finally, on Sect. 6, the conclusions and future research opportunities are presented.

2 Literature Review Background

2.1 Supply Chain Complexity

The complexity is one of the relevant issues mentioned on the SC literature. The SCC definitions present different principles but, in general, the common understanding is that SCC is a multifaceted phenomenon caused by several sources. Risk and uncertainty, technological complicatedness, organizational practice, large number of suppliers, mix of products, and manufacture processes multiplicity can be identified as key elements. Obviously, it is not easy to identify what just defines the SCC and which effects are key for an adequate decision-making process in the SC. The challenge is how to identify a clear complexity framework concept and the relevant variables that help to manage a complex decision-making process into the SC [7]. Data collected process is key, when used as a proactive attitude to react properly, answering tactical or operational non-planned issues that occur over the SC [8]. On the other hand, strategies that anticipate uncertainties, will be able to dampen turbulence and disruptions when operating on a complex environment [9].

2.2 Drivers in Supply Chain Complexity

The SC operations in a complex environment is constantly at risk, that can be classified as a positive or, a negative risk. For example, in a dual sourcing strategy, the negative effect of supply disruption could be converted in a positive effect, allowing to the chain do a self-balance cost, in case that, one of the suppliers increase the price due an own internal failure. Decision-making complexity must increase as the sequence flexibility for the parts in the production batch increases [10]. The flexibility is required to attend the high demand spikes, production mix, special situations, resources and capacity, quality model, and other dynamic product assortment. Supplier delays has a direct impact on a complex decision-making process and always challenge the tradeoff between SC costs and service level to customers. The Table 2 presents the main drivers in SC complexity.

Table 1. Drivers in supply chain complexity

Source: adapted from [12] and [13].

# Driver	Concept
1. Uncertainty	The lack of predictability and reliability of demand and of supply chain in processes. SC sources: customer demand, SC processes, and market conditions
2. Variability	Unexpected, large and variable changes in requirements over time. Difference among planned and actual elements in the chain. SC source: SC processes behavior
3. Multiplicity	Complexity covered by a combination of several elements such as product profile (raw material, semi-finished or finished goods), processes synchronization, act globally vs. locally, stakeholders alignment, clear targets definitions, etc. SC source: high quantity of components and multilevel structures contributes to an increase on SCC
4. Size	Relative number or volume of products or activities. SC source: minimal order quantity, production batches, lot sizes, number of suppliers, and product assortment
5. Speed	Required responsiveness across the supply chain in terms of throughput times, delivery times and frequencies. SC source: Short product life cycle, service level agreements, and real time track & trace
6. Diversity	Hybrid, homogeneity and heterogeneity systems (supplier, product, transportation modal). SC source: the level of customization of products and services offered to customers

The literature presents distinct models to identify the complexity of SC (see Sect. 2.1). The Table 2 shows the relevant models with a concept summary related to the drivers in SCC (see Sect. 2.2). The "model application effort" dimension was added as a seventh driver, in order to complement the analysis.

Table 2. Supply chain complexity models vs. drivers in SCC

			SCC drivers						
Author	Year	Concept summary	Uncertainty	Variability	Multiplicity	Size	Speed	Diversity	Effort
[12]	1998	The SCC triangle is composed by three elements: (a) deterministic chaos; (b) parallel interactions; (c) demand amplification. Some variables were inputted impacting the chaos (SC decision-making process; SC Control System)	●	●	●	●	N/A	N/A	++
[1]	2005	The complexity has two dimensions: (a) Internal organization - supplier-customer interface and dynamic environment, and (b) Organizational aspects - uncertainty and product technological intricacy	●	●	●	N/A	N/A	N/A	+++
[6]	2011	The model composition is (a) antecedents to SCC: supply chain complexity, supply chain decision-making complexity, moderators to the link between SCC, and supply chain decision-making complexity, and	●	●	●	●	●	N/A	++

(*continued*)

Table 2. (*continued*)

			SCC drivers						
Author	Year	Concept summary	Uncertainty	Variability	Multiplicity	Size	Speed	Diversity	Effort
		(b) moderators to the link between supply chain decision-making complexity and outcomes, and the performance outputs							
[14]	2012	The complexity is determined by the following main parameters: (a) number of elements and interrelations that set the system; (b) the degree of uncertainty that enters the system; (c) supplier leverage on the customer-requested product variety; and (d) geographical components that act on the system	●	●	●	●	N/A	N/A	+++
[15]	2013	The method estimates the operational (too called dynamic) complexity associated with the different stages of the SC, where each stage is identified by the alteration of data or material	●	●	●		●	●	+++
[16]	2015	There are two sub-streamers path in SCC: (a) SC as a complex adaptive system that have a capability to learn and adapt to the environment, or (b) SC as social network, using social network analysis method to understand how relational tier are	●	●	N/A	N/A	N/A	N/A	+++

(*continued*)

Table 2. (*continued*)

			SCC drivers						
Author	Year	Concept summary	Uncertainty	Variability	Multiplicity	Size	Speed	Diversity	Effort
		composed and how this connection affects the social capital, convergence, resource, and contamination in SC and networks							
[17]	2016	In accordance to the authors: the SCC is the detail degree of complexity and dynamic complexity. The SCC drivers can generate within the business unit (BU): internal drivers; or external drivers of decision-making processes and environmental factors. Disregarding this type or origin, the SCC can occur due to the commercial strategy or improper business practices (complexity dysfunctional)	●	●	●	N/A	N/A	N/A	++
[2]	2018	To [2] does not exist a unified concept of SC as Complex system. Complexity definitions are considered: (a) structural complexity; (b) functional complexity; and (c) modelling complexity	●	●	●	●	●	●	++

Source: authors. Legend: Model application effort: High (+++); Medium (++); Low (+); N/A (Not Applicable).

The summary of the models was evaluated in a cross reference (Table 1 vs. Table 2). As a result, it was found that the most adequate indication for this study is the model presented by Manuj and Sahin [6].

2.3 SC Risk Management

Tang defines SC risk management as the coordination and collaboration between various partners across the chain, in order to ensure the operations continuity and the business profitability [18].

Manuj and Mentzer broadened the concept of SC for global operations of risk management, defining it as being the process of identification and assessment of business risks and their losses through the application of appropriate strategies to coordinate logistics operations on a sustainable basis between different partners CS [19].

The type and the maturity level of the relationships among the various SC links can influence the operations performance. The information sharing level between the SC partners, the service level agreements and the delimitation of the work scope and responsibilities, represent the main relevant elements that would influence the uncertainty level and, therefore, the disruption risks related to that specific SC [20–22].

3 Methodology

An exploratory research approach was applied on this research development, and in order to validate the assessment framework developed, a test case was carried out in a real example.

The exploratory approach is recommended when a better understanding or a clarification on a given topic is required. It also allows flexibility to the research development and to validate the proposed assumptions [23].

Based on a literature review of the SCC and decision-making process subjects, an assessment framework proposal was developed and applied on a test case, in order to validate the model's applicability. On Sect. 4 is described the steps to apply the SCC assessment framework development.

4 Supply Chain Complexity Theoretical Assessment Framework

The SCC theoretical assessment framework proposal was developed through the 5 steps stated below and it is presented on Fig. 1.

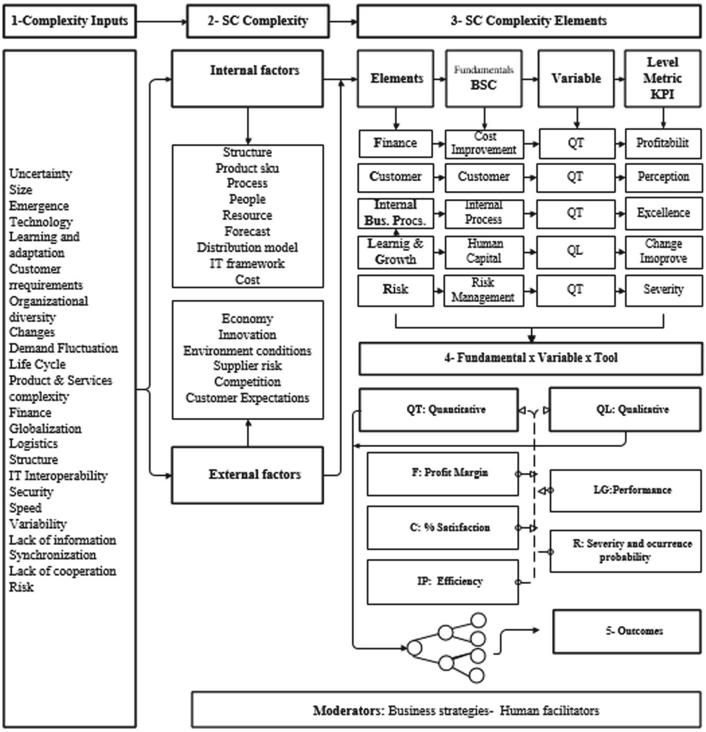

Fig. 1. Supply chain complexity decision-making integrated framework. Source: adapted from [6].

Step 1: identify which model could be adopted as a SCC assessment execution, aligned with the decision-making key drivers. The model presented by Manuj and Sahin [6] was extend and adapted to this work (see Fig. 1).
Step 2: develop an evaluation measurement to the respective SC complexity degree drivers: Uncertainty, Variability, Multiplicity, Size, Speed, and Diversity (see Sect. 2.2, Table 2).
Step 3: identify the relevant variables, qualitative and quantitative, to be considered on the decision-making process related to the SCC degree definition, using the Balanced Score Card (BSC) drivers as a reference and adding the risk management dimension on the scheme [24];
Step 4: choose the appropriate tool to the decision-making process based on the SCC degree (at this phase limited to a theoretical base platform);
Step 5: develop an implementation plan (actions and priorities) based on the assessment framework proposal (follow phase: mathematical basis, case studies and results analysis, application and simulation).

5 Test Case and Preliminary Results

An organization, so-called ABC (computer manufacturing), faced an inventory issue: raw material amount of ~U$K800, as a potential excess and obsolescence due to the product life cycle.

Problem Statement
The ABC Brazil plant need to convert this excess in saleable product (~1,980 servers), export and delivery on time (until 90 days) to the USA Distributor, assuring the sales out before the product life cycle status change to obsolete.

Variables Identification

Inventory cost: potential write plus additional raw material investment to conclude the product conversion from raw material: U$K235. Total at risk: U$M 1,035.
Logistics costs projection: transportation and warehouse materials handling.
Customer (Distributor): receipt and sale of all products before the obsolete life cycle start.

Scenarios

Scenario 1: No actions and keep the inventory write-off. Business impact of ~U$K800. Complexity element: finance.
Scenario 2: Work on the solution to avoid the potential business impact.
Complexity elements: financial, product life cycle, logistics services and customer satisfaction.

SCC Theoretical Assessment Framework Application
Scenario 1 represents the real finance impact in the business, without actions. Scenario 2 represents the most appropriate alternative chosen by the supply chain team, applying the assessment framework developed. The preliminary result was discussed and evaluated by the ABC SC specialists.

In this context, the complexity elements considered to the framework evaluation were:

(1) Finance - with a total investment of U$M 1,035 and revenue projection of U$M 1,609, the complexity level was classified by the specialists as high;
(2) Customer - considering an express shipment to the customer warehouse, with enough time to convert the inventory in sales out, the complexity level was defined as high;
(3) Internal business process - inbound and outbound logistics and production will absorb the additional workload, and the complexity was classified as high;
(4) Learning and growth - the transportation modal definition (cost optimization and delivery performance) was classified as low complexity level, as per the ABC SC team know-how;
(5) Risk - the operational risks identified was medium: quality of SC information, volatile demand, and sales assurance in the USA market (product life cycle).

Procedure

Complexity elements input to determine the SCC degree based on assessment framework model: 1 – low complexity; 3 – medium complexity; and 5 – high complexity. Based on the ABC SC team perception, the complexity degree was assigned to the key elements identified on the practical application.

These inputs enable the decision-maker to compare the complexity elements differences, and take the actions aligned by the scale complexity and the business strategy. The complete process construct, inputs related to this case, score calculation and analyses are represented on Fig. 2.

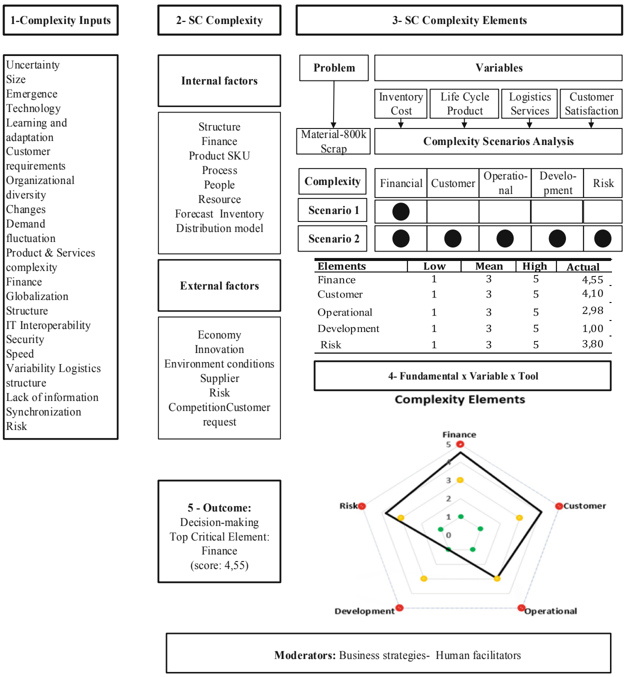

Fig. 2. Complexity elements in the framework construct and application. Source: authors.

6 Conclusions

This work aimed to develop a theoretical framework assessment model to support the decision-making process on SC network complex environment on a more assertive and pragmatic way.

Although the literature presents several studies on SC complexity, this research has combined new elements (complexity score determination based on the specific complex elements of the SC, BSC Drivers) to guide the decision-making process under a complex SC environment.

The test case application evidences the importance of the manager role as a guidance to the team during the process to validate the complexity elements measurement, using the proposal matrix elements degree. Does not only the score weight is decisive: the combination of the specialists understanding and experience, about the relevant variables on a complex SC, and the relation with the business strategy are key to support the decision-making process.

The model proposed and presented in this research is limited to one scenario with only one supplier and one customer. As a future step, could be developed a more robust framework, adding quantitative values to be evaluated. Despite that, the preliminary framework results show that is possible to improve the SCC decision-making with a more collaborative approach with the other business areas, assuring a complete identification of the relevant variables to be included on the assessment framework. A future framework development would encompass the product life-cycle dimension and how many nodes must be considering on the complexity analysis.

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