

# **Identifying LARG relationships in SCM through the House of Quality**

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## **Abstract**

In the current context of such high uncertainty in which supply chains are operating, implementing something from the Lean, Agile, Resilient, and Green (LARG) paradigms can promote competitive advantage in Supply Chain Management (SCM). However, the merge/mixture of paradigms implies trade-offs among the attributes of the supply chain, as some are positively related, generating synergies, while others are negatively related, generating divergences. The purpose of this paper is to identify the relationships between LARG paradigms in SCM. A decision-support tool regarding the LARG paradigms is proposed based on the House of Quality relationship matrix. To do so, a set of requirements to satisfy customer expectations as well as a set of performance measures must be identified. The two most appropriate sets, defined and ranked by a panel of experts, are used to build the relationship matrix, which is used to explore how each performance measure is related to each customer's expectation.

This work is an embryo of a new approach to the analysis of the interrelationships between the LARG paradigms in SCM. Such an approach will help academics and managers to better identify the trade-offs between the LARG paradigms, contributing to the development of more sustainable and competitive supply chains.

## **Keywords**

Lean, Resilient, Green, Supply Chain Management, House of Quality

## **1. Introduction**

Nowadays, the competitiveness of the supply chain (SC) is measured through the deployment of different management paradigms, for example, Lean, Agile, Resilient, and Green (LARG). These paradigms have different ways of deployment in the SC context.

The Lean paradigm involves eliminating waste and improving processes, removing non-value added activities along SC processes and at the same time trying to reduce costs and time; the Agile paradigm embodies flexible and timely actions in response to rapidly changing environments; and the Resilience paradigm aims to make the SC more resilient to unforeseen disturbances, effectively combating them or allowing the SC to return to the state immediately prior to the instant in which the disturbance occurs or progress to a new, more desirable state; finally, the Green paradigm focuses on consolidating environmental awareness into management practices (Carvalho et al. 2011; Cabrita et al. 2016; Suifan et al. 2019).

A correct understanding of the relationships between LARG paradigms is a starting point for putting their principles, techniques, attributes, practices, and tools into action (Carvalho et al. 2011; Duarte and Cruz-Machado 2011). A good structure of the SC is important not only to achieve effectiveness but also to give competitive advantages to companies (Buyukozkan and Berkol 2011). Therefore, LARG paradigms will help to define the best SC processes and flows.

Many aspects must be considered, namely whether the companies have their mindset oriented towards customers' satisfaction and expectations. Bottani (2009) states that the Quality Function Deployment (QFD) methodology can be

tailored for the agile context. Buyukozkan and Berkol (2011) consider the House of Quality (HoQ), the starting point of the QFD methodology, a key strategic tool to determine the design requirements for SCs that satisfy the customer requirements (CRs). In a study on the green SC, Haiyun et al. (2021) consider the HoQ an important tool for strategic Supply Chain Management (SCM). However, no studies were found in the literature that used the HoQ either in the strategic SCM or in another context, including the LARG approach. Duarte et al. (2019) also conclude that one of the current research challenges on the SCM is to understand how interrelationships among LARG paradigms, that result in conflicts, can be overcome.

The paper proposes the basis to help design LARG SCs. The objective is to present the starting point for exploring how each LARG requirement relates to SC's performance measures. The study shows that this research approach is still an emergent research topic and needs more development research.

Beyond the introduction, this piece of research is organized into four sections as follows: Section 2 presents the theoretical foundation on the characteristics of LARG SCs, and SC performance measures are addressed in assessing the influence of LARG paradigms on SCM. Section 3 presents an overview of the HoQ, the starting point of the QFD methodology. Section 4 presents the baseline of the HoQ matrix and suggests some examples of CRs and product engineering characteristics (ECs) for LARG SCs. The definition of the relationships between CRs and product ECs is also shown. Finally, Section 5 presents the conclusions and limitations of this work, and the direction of future research is outlined.

## **2. Literature Review**

### **2.1 The evolution of the LARG topic**

The acronym LARG in the SC context was coined in 2009 through the work of Carvalho and Cruz-Machado (2009). The original research idea was to analyse the integration of LARG paradigms in SCM, analysing the interrelationships among them, both synergies and divergences. Research around the LARG topic has already been carried out on the SCM thematic through a conceptual model of manufacturing (e.g., Carvalho et al. 2011; Duarte and Cruz-Machado 2011), using decision models (Cabral et al. 2012) or using an index model (Azevedo et al. 2016).

In this research topic, there are works based on automotive industry (Azevedo et al. 2016), seaport activities (Salleh et al. 2020), or shipbuilding (Ramirez-Pena et al. 2019) SCs. Also, LARG research can be identified based on business models (Cabrita et al. 2016), Industry 4.0 (Ramirez-Pena et al. 2019; Amjad et al. 2020; Raut et al. 2021), or quality management (Zanjirani et al. 2019). Sharma et al. (2020) made a systematic literature review to integrate LARG and sustainable paradigms.

In their work, Duarte et al. (2019) mention that “Despite the advances on LARG topic, there is still a need for more research. It is not clear how to manage SCs according to different philosophical orientations since by deploying different management practices to reach its performance goals, synergies and trade-offs can emerge”. Trade-offs can be defined as interrelationships between LARG paradigms that lead to conflicts or divergences.

### **2.2 LARG paradigms**

In the SCM literature, LARG characteristics are often referred to as practices or attributes. Each paradigm has its own definition and characteristics.

The Lean paradigm is deployed in all types of business, and in all kinds of SC processes (Cabrita et al. 2016). This paradigm, through continuous improvement, aims to eliminate waste and non-value-added activities, reduce costs and time, and increase both productivity and product quality. Lean SC considers different practices, such as i) inventory minimization, which can be zero in certain circumstances, ii) just-in-time production, iii) higher resources utilization rate, iv) shorter lead times, v) frequent interaction among SC entities, vi) single or dual sourcing; and vii) elimination of waste (Duarte and Cruz-Machado 2011; Carvalho et al. 2011). Lean increases the perception of each SC process (Duarte and Cruz-Machado 2011). Leanness performs best when there is a low variety of high-volume products and a predictable demand with supply certainty (Raut et al. 2021).

Another important element for modeling SCs is the Agile paradigm (Zarei et al. 2011). This paradigm allows answering in real-time to unpredictable market changes in an efficient way. Therefore, Agile is a paradigm that has the characteristics to be fast and vigorous, predicting the risks associated with SCs and trying to prevent them (Amjad et al. 2020). Consequently, the terms flexibility and speed are essential in Agile SCs (Al-Refaie et al. 2020). Furthermore, it generates a dynamic system where change, information flow, and decision-making are continuous (Duarte and Cruz-Machado 2011). It incorporates practices, such as i) inventory in response to demand, ii) excess

buffer capacity, iii) quick response to customer needs, iv) total marketplace visibility, v) dynamic alliances, vi) supplier speed, vii) flexibility, viii) quality, and ix) shorter lead times (Carvalho and Cruz-Machado, 2009; Carvalho et al. 2011, Salleh et al. 2020). Agility acts best when there is a wide variety of low-volume products, and when customer expectations are often unpredictable and supplier innovations and capabilities are difficult to control (Zarei et al. 2011; Raut et al. 2021).

The Resilient paradigm provides the organization with the ability to return to its normal state or even a better state, after having suffered a shock or disruption. Resilience can be asserted as the reduction of process risks to anticipate changes in markets (Amjad et al. 2020; Raut et al. 2021). Consequently, redundancy and flexibility are essential in a Resilient SC (Al-Refaie et al. 2020). A Resilient SC comprises different practices, such as: i) strategic inventory, ii) capacity buffers, iii) demand visibility, iv) small batches sizes, v) responsiveness, vi) risk-sharing, and vii) flexible transportation (Carvalho et al. 2011; Azevedo et al. 2011; Salleh et al. 2020). Resilience works best when there is a wide variety of products and when there is a risk that demand will be exceeded.

The Green paradigm is important in a SC to achieve organizational profit and market share objectives, reducing environmental risks and impacts. The Green SC paradigm responds to customer needs with environmentally friendly practices. Examples are: i) reduction of redundant and unnecessary materials, ii) reduction of replenishment frequency, iii) integration of reverse material and information flow in SC, iv) sharing of environmental risks, v) minimization of waste, vi) reduction of transportation lead time, vii) efficiency of resource consumption (Carvalho et al. 2011; Azevedo et al. 2011; Salleh et al. 2020). Greenness performs best when there is a low variety of products, whose principal characteristics are environmentally friendly products.

Indeed, LARG SC has a set of comparable and distinctive requirements to work well and improve the efficiency and effectiveness of a company. These requirements can be considered as the deployment of several LARG practices. Table 1 summarises some of those practices. These practices can be seen as the requirements that each SC paradigm must satisfy.

Table 1. Several LARG requirements  
(Adapted from: Azevedo et al. 2011; Zarei et al. 2011; Sallet et al. 2020; Amjad et al. 2021)

<b>Paradigm</b>	<b>Requirements</b>	<b>Paradigm</b>	<b>Requirements</b>
Lean	<ul style="list-style-type: none"> <li>• Just-in-time</li> <li>• Cycle/setup time reduction</li> <li>• High resource utilization rate</li> <li>• Information spreading through the network</li> <li>• Short lead time</li> <li>• Waste elimination</li> <li>• Product modularity</li> <li>• Usage common parts</li> <li>• Use of bar code container</li> <li>• Variability reduction</li> <li>• Continuous improvement</li> <li>• Knowledge management</li> </ul>	Agile	<ul style="list-style-type: none"> <li>• Speed in improving responsiveness</li> <li>• Responsiveness to unpredictable demand</li> <li>• To produce in large or small batches</li> <li>• Ability to change delivery times</li> <li>• Excess buffer capacity</li> <li>• Quick response to customer needs/claim</li> <li>• Total marketplace visibility</li> <li>• Technological unification</li> </ul>
Resilient	<ul style="list-style-type: none"> <li>• Demand-based management</li> <li>• Inventories and supply conditions</li> <li>• Lead time reduction</li> <li>• Strategic inventory/equipment</li> <li>• Demand visibility</li> <li>• Responsiveness</li> <li>• Risk sharing</li> <li>• Flexible transportation</li> <li>• Preparedness for incidents</li> </ul>	Green	<ul style="list-style-type: none"> <li>• Reduction in the variety of materials employed in products manufacturing</li> <li>• To work with product designers and suppliers to reduce and eliminate product environmental impacts</li> <li>• Source materials from environmental /ethical sources</li> <li>• Environmental risk sharing</li> <li>• Waste minimization</li> <li>• Renewable energy/initiative</li> <li>• Environmentally friendly packaging</li> <li>• ISO 14001 implementation</li> </ul>

	<ul style="list-style-type: none"> <li>• Responsible consumption</li> <li>• Carbon Footprint reduction</li> </ul>
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### 2.3 Supply chain performance

Appropriate SC performance measures are difficult to choose due to the complexity of such a system (Ruiz-Benítez et al. 2018). The number of different measures needed for SC assessment may differ based on the level of complexity (Ruiz-Benítez et al. 2018). An overview of the measures and indicators commonly used to assess the influence of LARG paradigms on SC performance is presented in Table 2.

Table 2. SC performance measures and indicators  
(Adapted from: Carvalho et al., 2012; Azevedo et al., 2011; Aramyan et al., 2007)

Measures	Indicators
Quality	<ul style="list-style-type: none"> <li>• Quality of delivery goods</li> <li>• Order-fulfilment rates</li> <li>• Customer complaints</li> <li>• Customer rejection rate</li> <li>• Percentage of materials remanufactured</li> <li>• Percentage of materials recycled or reused</li> </ul>
Delivery	<ul style="list-style-type: none"> <li>• Delivery speed</li> <li>• Shipping errors</li> <li>• On-time delivery</li> <li>• Responsiveness to urgent deliveries</li> <li>• Air emissions</li> <li>• Returning customers ratio</li> <li>• Total flow quantity of scrap</li> </ul>
Time	<ul style="list-style-type: none"> <li>• Lead time</li> <li>• Cycle times</li> <li>• Order-fulfilment lead time</li> </ul>
Flexibility	<ul style="list-style-type: none"> <li>• Excess capacity</li> <li>• Delivery flexibility</li> <li>• Transport flexibility</li> <li>• Volume flexibility</li> <li>• Customer satisfaction</li> </ul>
Inventory	<ul style="list-style-type: none"> <li>• Finished goods equivalent units</li> <li>• Level of safety stocks</li> <li>• Order-to-ship</li> </ul>
Cost	<ul style="list-style-type: none"> <li>• Manufacturing cost</li> <li>• Distribution cost</li> <li>• Warranty cost</li> <li>• Inventory carrying cost</li> <li>• Redundancy cost</li> <li>• Disposal costs</li> <li>• Recycling cost</li> </ul>

### 2.3 LARG relationships

According to Carvalho et al. (2011) and Duarte and Cruz-Machado (2011), the integration of the four paradigms can generate interrelationships. In their work, Duarte and Cruz-Machado (2011) indicate that “the traditional trade-off paradigm indicates that raising one aspect of performance implies reductions in others. The trade-offs are important in order to identify which of them are relevant for the operations and which require improvement”.

Several interrelationships that result in conflicts can be encountered in literature, such as the following:

- The Lean paradigm that uses just-in-time (JIT) delivery of small lot sizes may require greater transportation, packaging, and handling, i.e., more energy consumption and produces a higher level of atmospheric emissions, which goes against the Green paradigm (Carvalho et al. 2014; Azevedo et al. 2016);
- The Resilient paradigm requires the utilization of flexible transportation that allows SCs to be more responsive to overcoming disruptions, such as interruptions in material flows and speeding up the delivery of material, but the use of alternative or urgent transportation can lead to an increase in CO<sub>2</sub> emissions and higher transportation costs, which goes against Lean and Green paradigms (Carvalho et al. 2014);
- The Resilient paradigm asks for the presence of strategic inventory, reducing the companies' vulnerability to unexpected events that may cause disturbances in the supply of the materials, but can generate material obsolescence and hide the causes of a weak SC performance instead of Lean and Agile paradigms, which propose the minimization of inventory levels (Azevedo et al. 2016; Carvalho et al. 2011);
- Agile and Resilient paradigms require an additional capacity buffer that allows responding to changing customers' needs or unexpected events, but this is not in line with Lean and Green paradigms, as Lean and Green paradigms are characterized by the efficiency of resources consumption and a higher utilization rate through the SC (Carvalho et al., 2011).

According to Carvalho et al. (2014), "by recognizing these types of conflicts, companies may be able to identify trade-offs or develop solutions that mitigate undesirable consequences."

### **3. The House of Quality**

#### **3.1 An overview**

The House of Quality (HOQ) is the core tool of the QFD methodology aiming to provide a priority list of technical design elements, which derive from CRs that have been evaluated and ranked by importance (Luo and Zhu 2020). Luo and Zhu (2020) explain the different "modules", which are as follows: i) CRs input (the left "wall" of the HoQ, also known as the "voice of the customer"), ii) competitive evaluation matrix to evaluate the products or services of the company versus its competitors (the right wall); iii) technical requirements adopted by the company to meet the customer demands (ceiling); iv) relationship matrix to measure the relationship between the customer's and technical requirements (room); v) correlation matrix to assess the correlation relationship between the technical requirements in the ceiling (roof of the HoQ), and vi) the output of the HoQ (the baseline) (Luo and Zhu 2020).

The HoQ is a strategic tool in product development for translating CRs – "what", into appropriate product ECs - "hows" (Bottani 2009). The CRs describe the customer's needs and/or expectations. Therefore, CRs are usually called the Voice of the Customer (VoC). On the other hand, ECs are variables, usually measurable, that are used to assess in what extent the CRs are satisfied. The relationships between CRs and ECs are established in the relationship matrix, indicating how the i-th EC performs against the j-th CR (Bottani 2009).

In other words, the relationship matrix assesses how much each EC affects each CR. Usually, these relationships are established based on team consensus. In the traditional application of the HoQ, the degrees of these relationships are expressed by three graphical symbols (weak, medium, strong), which are translated into a rating scale, such as 1-3-9 or 1-5-9, respectively (Bottani 2009). Determining the importance of CRs and ECs is a very important step of HoQ (Buyukozkan and Berkol 2011).

Examples of research work applying the HoQ to analyse the LARG paradigms are encountered in literature, but only to a single paradigm: relative to the Resilient paradigm (Luo and Zhu 2020), to the Agile paradigm (Bottani, 2009) or to the Lean paradigm (Zairei et al. 2011) and Green paradigm (Yang et al. 2012). Bottani (2009) proposed an approach where HoQ principles are combined with fuzzy logic to achieve agility in the new product development field. Also, Zairei et al. (2011) proposed an AHP–Fuzzy–HoQ to achieve Leanness in food SCs (Figure 1).

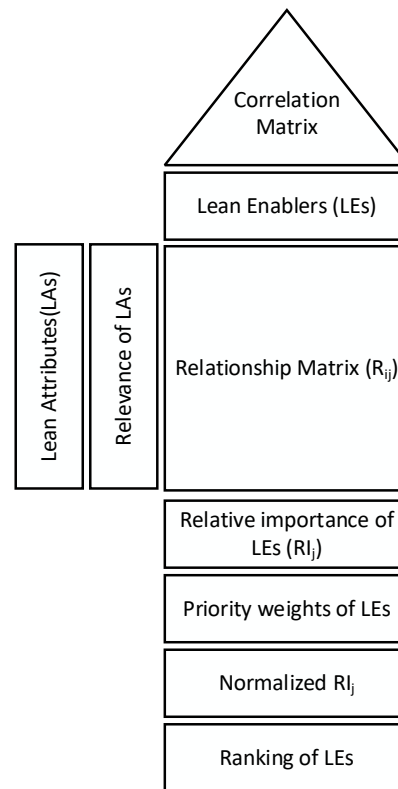


Figure 1. Generic HoQ to achieve Leanness  
(Source: Zairei et al. 2011)

The approaches developed by Bottani (2009), Zairei et al. (2011), Yang et al. (2012), and Luo and Zhu (2020) only allow studying a single paradigm. However, there are interrelationships between Lean, Agile, Resilient, and Green paradigms. This study intends to extend these works by developing an HoQ framework that allows studying these relationships in an integrated way.

### 3.2 The relationships through the HoQ

The first step in defining an HoQ is the identification of CRs. Therefore, it is important to define who the customers are because the CRs are the needs and/or expectations of LARG paradigms that, for example, a manufacturer wants to see satisfied by their suppliers and logistics providers. In a quality system, these requirements can be defined in order to meet customer needs or/and customer value. Thus, it is desirable to identify the LARG CRs considered in the HoQ and determine the ECs for SCs. To build the relationship matrix, it is necessary to define the ECs that suppliers and logistics providers will use to evaluate to what extent they are satisfying the CRs set by the manufacturer. These ECs are variables used to evaluate the performance of the LARG SC, which were defined based on the CRs (see Figure 2).

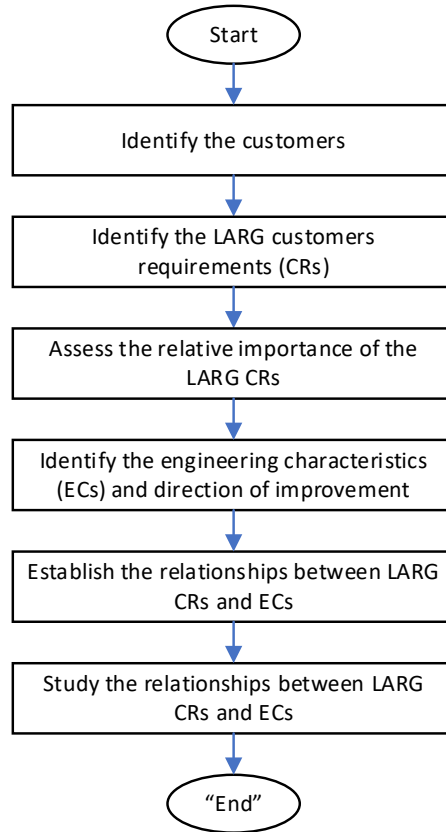


Figure 2. Stepwise description of the study

The CRs considered in this study were defined based on each paradigm's requirements. A qualitative approach based on a panel of experts has been used for achieving such an objective. The expert panel was composed of four researchers with a large experience in the field of Lean, Agile, Resilient, and Green SCM. The CRs selected for the pilot study are as follows: i) for the Green paradigm the defined CRs were: "Low consumption of hazardous and toxic materials (in production)" (CR1) and "Environmentally friendly consumption of energy/water" (CR2); ii) from an Agile perspective the defined CRs were: "Ability to assure short delivery lead times" (CR3); iii) from a Resilient perspective the "Material redundancy (higher inventory level than necessary)" (CR4); and iv) from an Agile and Resilient perspective the "Strategic inventory" (CR5), "Flexible transportation (alternative transportation modes)" (CR6), and "Quick response to unpredictable problems (in production and transportation)" (CR7). These CRs are a subset of a more complete list of LARG requirements and were chosen to illustrate our approach.

Once the CRs have been identified, the research team defined the following ECs for each CR: "Amount of hazardous and toxic materials used (in production)" (EC1); "percentage of energy consumption coming from renewable sources" (EC2); "Lead time (in days)" (EC3); "Inventory surplus (in days)" (EC4); "Inventory level (in days)" (EC5); "Number of alternative transportation modes" (EC6); and "Quickness in solving production problems" (EC7). It must be stressed that one EC can be related to more than one CR (see Figure 3).

A scale of 1-3-9 is used instead of 1-5-9 since the intent is to bring out the strong relationships between ECs and CRs. The intensity of the relationships shown in Figure 3 was defined by the expert panel as it is common practice in QFD applications. From the matrix, it is possible to conclude that the "Lead time" (EC3) affects in different ways the "Ability to assure short delivery lead times" (CR3), "Material redundancy (higher inventory level than necessary)" (CR4), "Strategic inventory" (CR5), "Flexible transportation (alternative transportation modes)" (CR6), and "Quick response to unpredictable problems (in production and transportation)" (CR7). Clearly, EC3 has a strong relationship with CR3, a medium relationship with CR5 and CR6, and a weak relationship with CR4 and CR7. These CRs and ECs, as well as their relationships, represent the preliminary results of this innovative research.

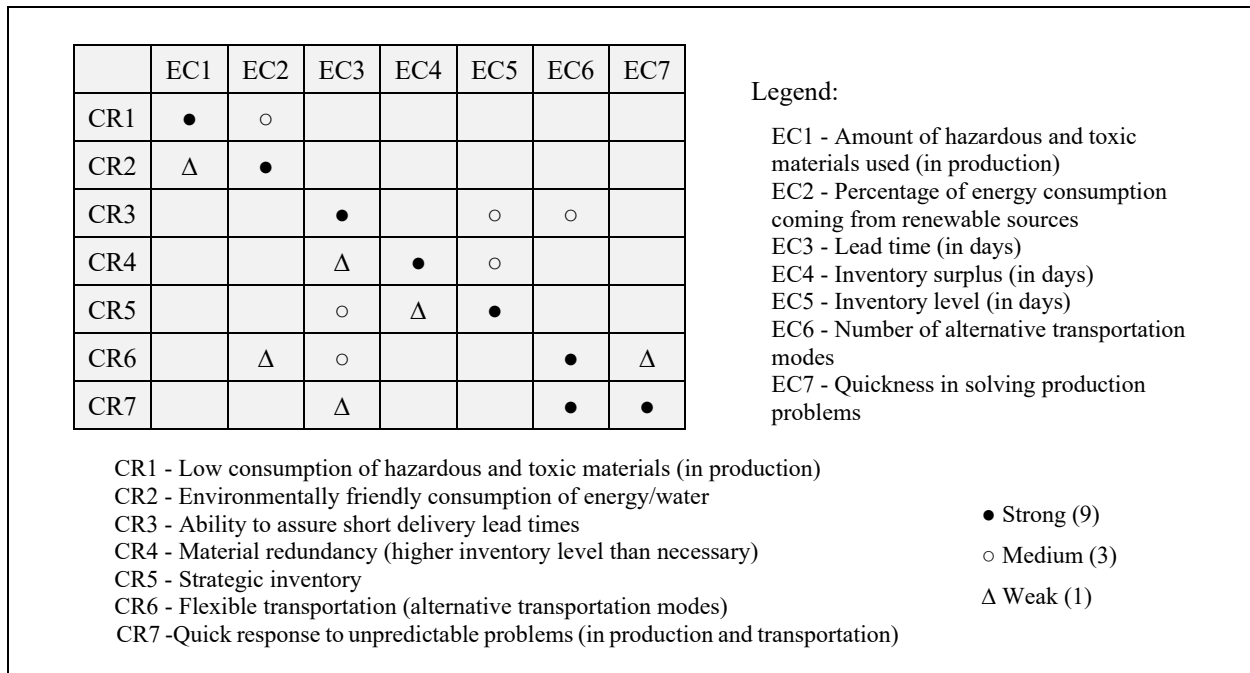


Figure 3. A subset of the relationship matrix

#### 4. Conclusion

The relationship between customers' needs and performance measures is a challenging subject that this piece of research tried to address. The adopted approach, based on the principles of the QFD, proved to be promising regarding the ability to characterize complex relationships, notably those associated with Lean, Agile, Resilient and Green paradigms. This integration provides a framework for designing SCs that can cope with synergies and conflicts among those paradigms. The exploratory research presented will be further developed, aiming at a generalization that can support adjustments to specific SC contexts, such as those that characterize the automotive industry or healthcare systems.

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## **Biographies**

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**Susana Duarte** holds a Ph.D. in Industrial Engineering. Presently she is an Assistant Professor of Industrial Engineering at School of Science and Technology of the Universidade NOVA de Lisboa, Portugal. She lectures several courses on topics related to industrial engineering including, production management, industrial management and strategy, industrial engineering, logistics, decision models, among others. She is a research member of UNIDEMI Research Center where develops their investigation in the area of lean manufacturing, green management, lean-green supply chain, and performance measurement systems. She has published scientific papers in several international refereed journals and international conferences proceedings. She was awarded Excellence Award from Emerald Group Publishing, a Teaching Excellence Award from IEOM society and three awards from International Conferences. She is a member of the board of the Portuguese Institute of Industrial Engineering.

**Ana P. Barroso** received her PhD in Systems Engineering from the Universidade Universidade Técnica de Lisboa in 2003. She is an Assistant Professor of Industrial Engineering at School of Science and Technology of the Universidade NOVA de Lisboa, and a researcher at the UNIDEMI Research Center. She lectures several master's courses, supply chain management, forecasting models, simulation, and operations management. Her research interests are centered on Industrial and Management Engineering topics, namely those aimed at efficient and effective management of supply chains and industrial and logistical systems; in particular, those that encompass a modeling approach or involve simulation. She has published several scientific papers in peer-reviewed international journals and international conferences proceedings. She has also published some book chapters and participated in national and international research projects.

**Rogério Puga-Leal** received his PhD in Industrial Engineering from the Universidade NOVA de Lisboa in 2000. He also holds post-graduations in Bank Management and Quality Engineering. He is an Associate Professor at the School of Science and Technology from the Universidade NOVA de Lisboa, and a research member of UNIDEMI Research Center. His research interests are focused on Industrial and Quality Engineering topics, notably those that focus services environments. Among others, his research topics include SPC in services, Lean Services, etc.. He is author of textbooks on the fields of applied statistics and Quality Management. He publishes regularly in indexed journals and conferences. In 2016, he was awarded the prize given by the Portuguese Association for Quality (APQ) to the best paper on the journal "Qualidade", and in 2019 he received the Santander Award for Research on Corporate Social Responsibility, along with three colleagues from the University of Navarra.