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Master's Thesis

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Improvement of the Ecosilient Index

MEMORY

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Review

The Ecosilient Index, originally proposed by the authors Susana G. Azevedo, Kannan Govindan, Helena Carvalho and V. Cruz – Machado, is an integrated index that reflects simultaneously the resilience and the greenness of automotive companies and their supply chains. This index, based on a combination of supply chain management practices related to green and resilient paradigms, is a useful tool that reduces a complex situation to a single number, helping companies to understand their supply chain's overall resilience and greenness and providing them a clear baseline for measuring their progress and improvement in both fields.

The main objective of the present Master's thesis is to improve this Ecosilient Index, in order to help automotive supply chains to better determine their overall resilient and green behaviours. For the development of the mentioned objective, it is first necessary to conduct a comprehensive review of the literature on resilient and green supply chains, in order to draw a global picture of both of them: broad definition, historical evolution and analysis of the resilient and green practices that are currently being implemented. Then, an overview of the automotive sector and a study of the present trends of the sector regarding resilience and greenness are provided, as the Ecosilient Index is focused on the automotive industry.

Thanks to all the information compiled, some suggestions aimed at improving the current Ecosilient Index are proposed. First of all, a total of four supplementary practices have been suggested to be added in the combination of green and resilient supply chain management practices used in the original Ecosilient Index. Second, the relationships between both paradigms, resilient and green, have been examined. Last, but not least, some modifications have been applied in the construction of the Ecosilient Index.

Finally, future research is needed as the improved Ecosilient Index is still at a theoretical level and has not been applied in real automotive supply chains. Therefore, it would be advisable to put into practice the two Ecosilient Indexes, the original and the new one, in order to compare them and validate the improvement suggestions proposed in the present Master's thesis.

Summary

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1. Introduction

Nowadays, due to the uncertainty of the global economy, the political and social instability, the use of new technologies and the climate change, the number and types of threats that can undermine a supply chain are greater than ever [1]. At the same time, in today´s globalised business environment, with supply chains spanning many countries or even continents, it is inevitable that disruptive events would menace the smooth flow of materials in supply chains even if they occur in a remote place [2]. If not managed properly, these events could cause to supply chains a drastic loss in productivity, profitability and competitive advantage among others [3]. Therefore, supply chain vulnerability has become for many companies a major concern.

In order to overcome possible disruptions and survive in today's uncertain and turbulent markets, supply chains should be more resilient. In the past, in order to survive in the world market, supply chains had to focus on achieving low cost, high quality, short lead time and high service level. However, today, the competitiveness of companies and supply chains also depends on their resilience [2].

On the other hand, the environmental sustainability of supply chains cannot be disregarded. Due to the growing environmental concerns among customers and the increasing environmental regulatory legislation, many companies have started to integrate environmental thinking into their supply chain management and adopt green practices. These practices contribute to reduce environmental risk and impact, but also to gain competitive advantage and to improve long-term profitability [4].

In the recent years, many research studies have shown the importance of considering both resilient and environmental paradigms in supply chains. By combining resilient and green practices together, companies can enhance their sustainability, identify strategic risks, create multiple business opportunities, improve their performance and, therefore, increase their competitiveness [5].

In spite of the importance of both paradigms, there is still not a proper way to measure them. For this reason, the authors Susana G. Azevedo, Kannan Govindan, Helena Carvalho and V. Cruz – Machado propose an integrated index, the Ecosilient Index, which reflects simultaneously the resilience and the greenness of companies and their supply chains. This index is based on a combination of supply chain management practices related to the green and resilient paradigms [5].

This Ecosilient Index is a simple and useful tool that reduces a complex situation to a single number, helping companies to understand the supply chain's overall resilience and

greenness and providing them a clear baseline for measuring their progress and improvement in both fields.

1.1. Objective of the project

The main objective of this project is to improve the current Ecosilient Index, in order to help automotive supply chains to better determine their overall resilient and green behaviours.

1.2. Methodology of the project

For the development of the present thesis, it is first necessary to conduct a comprehensive review of the literature on resilient and green supply chains, in order to draw a global picture of both of them: broad definition, historical evolution and analysis of the resilient and green practices that are currently being implemented.

Then, an overview of the automotive sector regarding greenness and resilience is provided, as the Ecosilient Index is focused on the automotive industry.

Finally, thanks to all the information compiled, some suggestions aimed at improving the current Ecosilient Index are proposed.

2. Previous concepts

Before examining resilient and green supply chains, it is first necessary to define some previous concepts that would help provide a better understanding of them.

2.1. Supply chain

In the past, companies were considered to be the highest unit studied during optimization and performance. However, at present, this view is insufficient; the definition of the system is wider and is now represented by supply chains [6]. In other words, in present-day business, supply chains compete instead of companies and must be managed as a single entity.

Several authors have come up with different definitions that tend to overlap in many cases with the supply chain being defined, for example, as “the network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer” [7], or “the network that links various agents, from the customer to the supplier, through manufacturing and services so that the flow of materials, money and information can be effectively managed to meet the business requirements” [8]. According to the Council of Supply Chain Management Professionals (CSCMP), a supply chain refers to both “the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user; and all vendors, service providers and customers are links in the supply chain” [9].

Thus, supply chains are dynamic and have many stages. It is important to emphasise that not only materials and information pass through the supply chain, but also financial or money flows.

A simple supply chain, as shown in Figure 1, generally includes suppliers, manufacturers, distributors, retailers and customers. In the upper part of the supply chain, manufacturers receive materials from the suppliers and convert them into goods, adding them value. Then, distributors distribute these products to retailers, who can easily reach the target costumers. In parallel with these materials and products flows, there are continuously informational and financial interchanges between the different members of the supply chain. However, customers can also obtain the products directly from the distributors or the manufacturers, so all the stages of Figure 1 are not always necessary and can vary. The stages depend in fact on the product and the supply chain concerned.

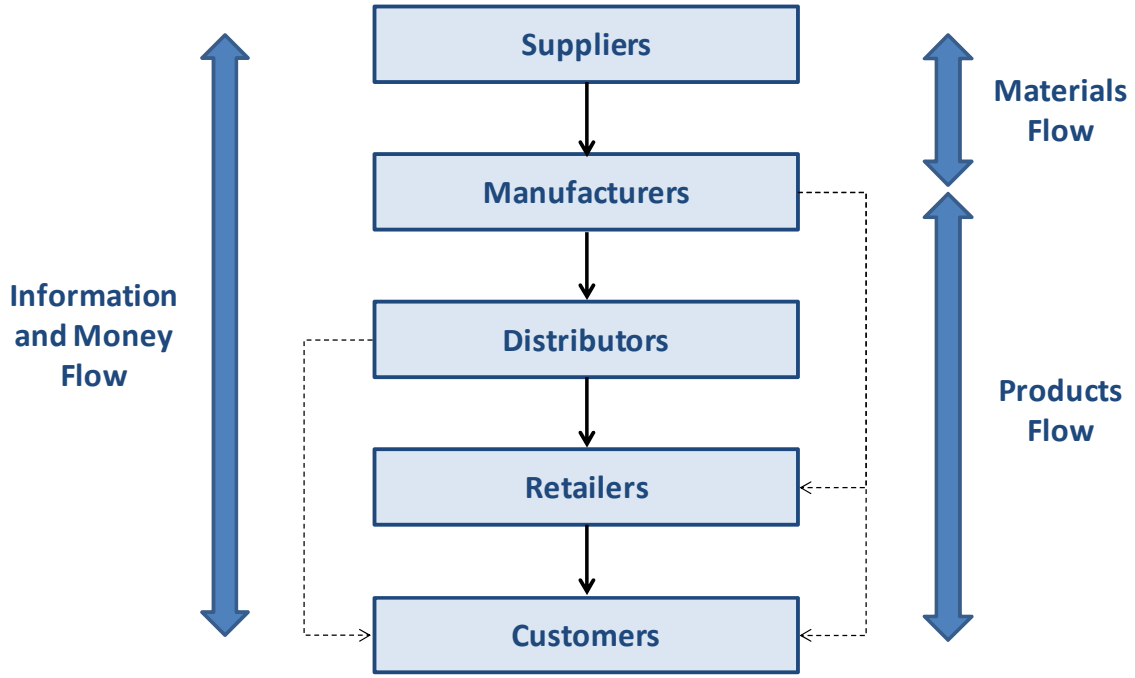

Figure 1: Supply chain stages

2.2. Supply chain management

The concept "supply chain management" was originally introduced in 1982 by the consultants Oliver and Webber. Since then, managing supply chains has become one of the main issues and line of research for academicians and practitioners.

As "supply chain", "supply chain management" is also a general term that different researchers of the field conceptualize differently. Therefore, listing some definitions can help understand the nature of supply chain management and what activities it includes.

As defined by the Council of Supply Chain Management Professionals (CSCMP), supply chain management "encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes the coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers" [9]. Supply chain management is also viewed as the "management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at lower cost to the supply chain as a whole" [10], or the "management of material, information and financial flows through a network of organizations (suppliers, manufacturers, logistics providers, distributors, retailers) that aims to produce and deliver products or services for the consumers. It includes the coordination and collaboration of processes and activities across different functions such

as marketing, sales, production, product design, procurement, logistics, finance and information technology within the network of organizations" [11]. Last, the discipline of supply chain management integrates supply and demand management within and across companies, and deals with the selection of the most adequate strategies and methodologies to facilitate the optimal flow of materials and information along the supply chain [2].

All the above definitions suggest that, in order to achieve final customer satisfaction, supply chain management manages the integration of companies' activities and processes upstream and downstream in the supply chain, such as procurement, production, distribution, finance and marketing, and the flow of materials, products, information and money between the supply chain companies [12]. Supply chain management is customer centered, and seeks to maximize the difference between the value generated for the final costumer and the total cost incurred across all stages of supply chain. In other words, the main objective of supply chain management is to offer improved customer value and satisfaction at the best possible cost, competitive advantage and long-term performance. Last, but not least, coordination and cooperation among all members of the supply chain is essential to improving the cost and the customer service.

3. Resilient Supply Chains

3.1. Introduction

Nowadays, markets are increasingly uncertain and turbulent. Over the last years, many types of unpredictable disasters have occurred: wars, terrorist attacks, earthquakes, tsunamis, strikes, economic crises, currency fluctuations, computer virus attacks...

At the same time, in order to boost the financial performance of the supply chains, numerous supply chain executives have implemented various initiatives to increase revenues (such as increasing product variety and new product introduction), to reduce cost (reducing supply base and reducing inventory, thanks to Just-In-Time[1] inventory system (JIT) or Vendor Managed Inventory[2] (VMI)) and to reduce assets (for instance outsourcing manufacturing). However, these trends have made supply chains more vulnerable to business disruptions in a turbulent environment [11].

In consequence, as supply chain risks have increased over the last years, managing and mitigating that risk has become for many companies one of their main concerns. In order to survive in the market fluctuations, it is no longer sufficient to focus on service optimization or cost minimization: supply chains must also be able to overcome disturbances that may affect their performance, that is to say, supply chains must be resilient.

3.2. Supply Chain risks

Risks in supply chains represent the possibility that unexpected and unfortunate events cause a negative impact on the normal operations or prevent activities from being implemented as planned, affecting or disrupting the materials, products or information flows within the chain [13]. There is a large variety of risks, which come from multiple sources and can have unpredictable consequences.

Supply chain risks can be classified in many different ways and from different perspectives. However, at its simplest, risks can be categorized in three main groups, which can be further sub-divided to produce a total of five categories [13] [10]:

- **Internal to the firm**
    - Process risks
    - Control risks
- **External to the firm but internal to the supply chain network**

[1, 2] *See definitions in the Glossary*

  - Demand risks
  - Supply risks

- **External to the network**
  - Environmental risks

This classification is detailed in the following sections.

3.2.1. Internal to the firm

These risks emerge from the own operations of a firm or an organization [13]. The first sub-category, process risks, is related to disruptions in processes, which are the sequences of value-adding and managerial activities undertaken by the firm [10]. In other words, this sub-category includes all the risks that can affect the internally owned or managed assets of the firm and the reliability of the supporting infrastructure, transport or communication.

The second sub-category, control risks, refers to risks arising from the application or misapplication of all the rules, policies and procedures that govern how an organization exerts control over the processes [10]. These rules and policies may be, for instance, batch sizes, order quantities, safety stock, transport management policies, etc.

3.2.2. External to the firm but internal to the supply chain network

These risks arise from the interactions between all members of a supply chain and are principally due to both a lack of cooperation between supply chain members and a lack of visibility within the network [13].

The first sub-category, demand risks, relates to potential or actual interruptions or disturbances to the flow of products, materials or information within a supply chain network, between the focal firm and the market [10]. Demand risks involve all the uncertainties regarding product demand, product life cycle and outbound logistics flows and are caused by unpredictable or misunderstood customer demand.

The second sub-category, supply risks, relates to potential or actual interruptions or disturbances to the flow of products, materials or information within a supply chain network, upstream of the focal firm. In particular, it relates to the processes, controls, asset and infrastructure dependencies of the organizations upstream of the focal firm [10].

3.2.3. External to the network

These risks result from the interactions of supply chains with their environment and are totally

outside of their control [13]. Environmental risks consist of external uncertainties caused by economic, social, political, technological or climate factors, including the threat of terrorism.

Environmental risks can impact upon any node or link through which a supply chain passes. They can either directly affect the focal firm, or the supply chain members located upstream or downstream of the focal firm, or the market place itself [10].

In Figure 2, the links between each of these five risks sub-categories are summarized.

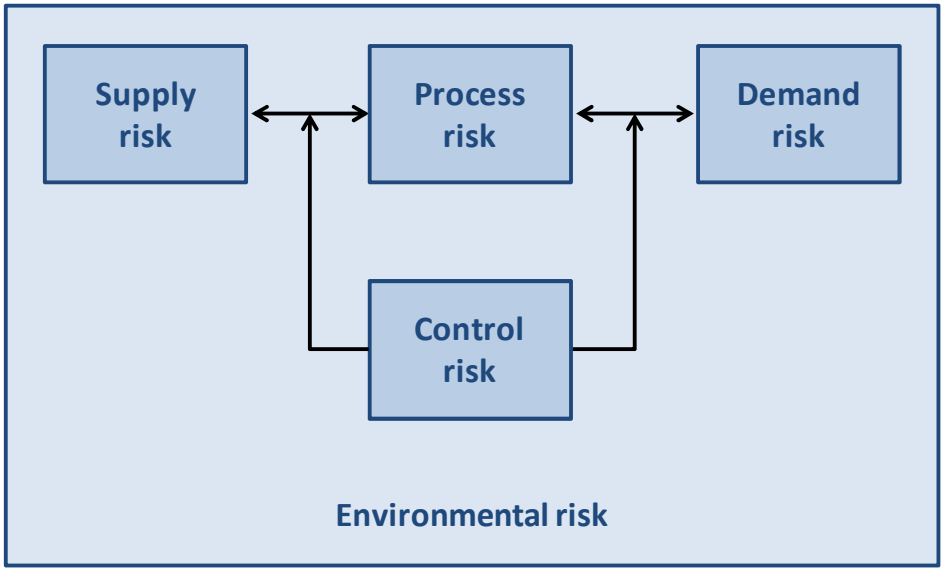

Figure 2: Sources of risk in a supply chain

3.3. Supply chain risk management

Supply chain risk management is considered a relatively new discipline and an evolving field [14]. According to the relevant literature, supply chain risk management is the identification and management of supply chain risks through coordination and collaboration among the supply chain partners, so as to reduce supply chain vulnerability as a whole and to ensure profitability and continuity [11][15].

Effective supply chain risk management is crucial to a successful business, as supply chain disturbances can have a significant impact on performance, profitability, operating income, sales, inventories and end-customers' satisfaction [16]. However, it is a competence that many enterprises have yet to develop. Indeed, the majority of companies do not have structured supply chain risk management systems [14].

3.4. Defining supply chain resilience

Supply chain resilience is still a new area of management research to be explored, although it is currently taking on more significance due to the fact that the number and types of risks to which supply chains are exposed are today greater than ever [10].

Resilience is a noun commonly used in the language. Broadly speaking, it means the ability of a system to return to its original after a disturbance [6]. The origin of the term comes from the science of materials, where it refers to the physical property of a material to recover its initial shape after a deformation that does not exceed its elastic limit [17]. Then, the use of the term continued to expand, and now it is commonly used in many areas of research, ranging from social sciences to engineering sciences: in ecology, it means the capacity of an ecosystem to resist damage and recover quickly after a perturbation such as, for instance, a fire, a deforestation or a flooding; in psychoanalysis, it is defined as the ability to withstand a trauma and rebuild after it; and, in social science, resilience means the ability of a community to deal with long-term stress [2].

The concept of resilience also expanded to the area of supply chain management, where several authors have proposed different definitions. According to [10], resilience is the ability of a supply chain to bounce back from any disruptive situation. Supply chain resilience is also viewed as the capacity of any members of a supply chain to react to disruptive events and maintain normal activities following a disruption [17]. As stated in [2], it is the capability of a supply chain to return quickly to its original state or move to a new one, more desirable, after being disturbed. For the Council of Supply Chain Management, it describes the level of hardening of supply chains against disasters [9]. Finally, as reported by [18], supply chain resilience no longer implies only the ability to manage risk; it now assumes that the capability to manage risk means being better positioned than competitors to deal with, and even gain advantage from, a disruption occurrence.

All the definitions mentioned above agree that resilience provides the ability to cope with unexpected disturbances and to mitigate their effect, but of course it does not stop their occurrence. Since disruptions are inevitable, firms need to develop resilient capabilities. However, increasing the degree of resilience in supply chains is neither an easy nor a short-term goal [6].

3.5. Practices for developing resilient supply chains

Resilient practices will help disrupted supply chains to recover to their original state, or even desired state, within a reasonable time and cost, as well as to soften the impact of disturbances [2].

According to the literature, resilient supply chains can be characterized by the following key attributes [10]:

- **Supply chain reengineering,** as traditional supply chains need to be redesigned to integrate resiliency into their design.
- **Collaboration** between all supply chain partners, in order to better identify and manage risk.
- **Agility,** as being able to react quickly to disturbances is fundamental in uncertain environments.
- **Demand management,** to influence or manage demand in case of a disruption.
- Driving **cultural change**, as it is one of the major enablers of resilience.
- **Security,** as it is necessary to design supply chains for both security and resilience.

These six key attributes and their main respective practices, which will be discussed in detail below, are summarized in Figure 3.

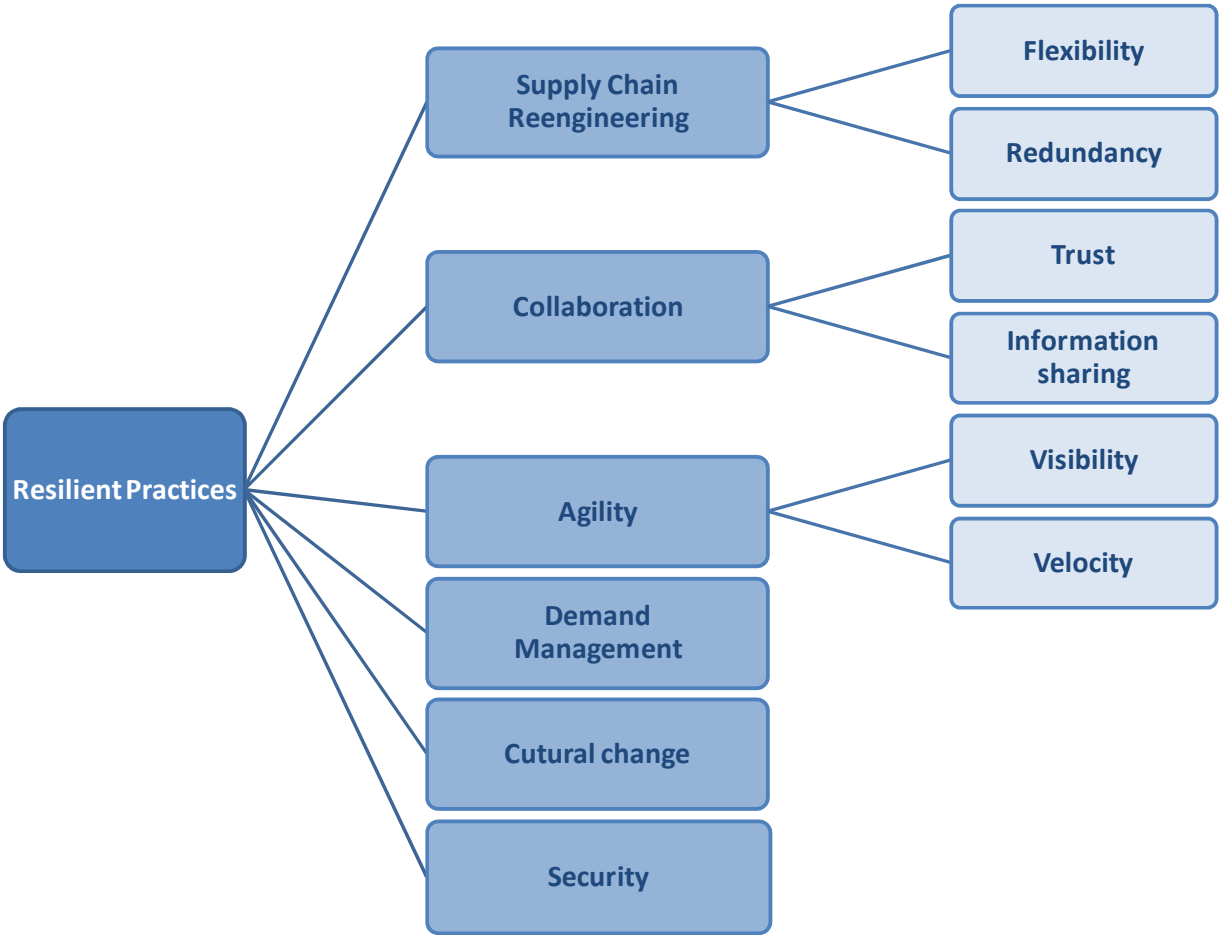

Figure 3: Resilient supply chains framework

3.5.1. Supply chain reengineering

Conventionally, supply chains have mainly been designed to achieve cost optimization and customer satisfaction, and the incorporation of resilience was not common. However, as the risks to which supply chains are exposed are becoming more significant, supply chains need to be redesigned in order to introduce resiliency into their design [19].

There are certain characteristics that, if engineered into a supply chain, can improve its resilience. Many authors have stated that adopting a flexible and redundant hybrid approach can increase the ability of supply chains to cope with disturbances [10] [17][19].

3.5.1.1. Flexibility

A flexible supply chain has the ability to withstand disruptions and to adapt to the changing requirements of its environment and stakeholders with minimum time and effort and without increasing significantly its operational costs [3]. In other words, flexibility involves creating capabilities within the supply chain that will enable organizations to respond quickly and efficiently to problems and to minimize the impact of disruptions or of sudden shifts in expectations or demand. These capabilities are mainly developed through investments in resources and infrastructure before they are actually needed [20]. Initiatives to improve flexibility would include, for instance, adopting sourcing strategies that allow switching of suppliers, designing production systems that can accommodate multiple products, developing good relationships with suppliers and developing a multi-skilled workforce [17].

Obviously, having a flexible supply chain with several strategies open and able to reallocate resources when needed is not the lowest cost option, but it helps reducing vulnerabilities and the impact of a disruption when it occurs [10]. For instance, in case of a shipping port shuts down unexpectedly due to a labor strike or a natural disaster, supply chains with alternate distribution points or modes of transportation will be able to shift quickly to another option and, consequently, will be less affected.

There are various flexibility practices that can increase supply chain resilience, being the main ones detailed below.

- ***Postponement***

Postponement strategy refers to the ability of a supply chain to design product and processes so as to move forward – i.e. to postpone – as many operations and decisions as possible to a much later point in the supply chain, to better recognize and meet customer's need [21]. In order to be able to delay the point of product differentiation as late as possible in the production stage, this strategy needs product and process design concepts such as

standardization, commonality, modularity and operations reversal [11]. In other words, the firm will first produce a generic product based on the total aggregate demand of all products and, then, will differentiate or customize the generic product later on, after obtaining accurate information about customers' preferences.

Postponement helps supply chains to adapt and respond efficiently to sudden demand fluctuations and unexpected disruptions [21]. Keeping products in semi-finished forms enables to move products from surplus to deficit areas, increases fill rates and improves customer service without increasing inventory costs, as products are completed only when more accurate demand information becomes available.

- ***Standardization***

Standardization increases supply chains flexibility, by offering interchangeability. There are three different levels of standardization:

- Processes: Standardization of a manufacturing process for similar products
- Products: Design of standardized products for comparable requirements
- Components: Use of common components in different products

Companies can use standard production facilities, processes, parts and components to be able to reallocate resources where the need is greatest and, consequently, to respond quickly to disruptions. By relying on similar or even identical plant designs and processes across the supply chain, firms are able to move production among facilities when needed, from one disrupted facility to another. Furthermore, by using generic and interchangeable parts in many products, companies can find an alternative supplier for components, in case the supplier is disrupted, or borrow them from another plant with available inventory [18].

Standardization not only provides flexibility in case of a disruption occurs, but also efficiency and cost effectiveness, thanks to the simplified manufacturing processes and the economy of scale.

By using standard components, companies use fewer parts for the same products, so the cost to order, handle and maintain inventory is reduced. On the other hand, having to change the production processes and the design of the products requires significant costs and time during the implementation phase, as companies must reconfigure the supply chain network and ensure that the reengineered products reach the desirable quality standards. However, the cost benefit analysis in the long term will be positive and the benefits for having standard parts and processes will compensate the investment needed at the beginning [12].

Of course, in case of a plant is disrupted, standardization alone is not enough and contingency plans are required: companies will need both alternative suppliers, to provide

extra stock to the alternative facility if needed, and flexible transportation, to be able to reroute components to the alternative plant and then send the products to the corresponding customers with no delays.

- ***Flexible manufacturing***

Flexible manufacturing refers to manufacturing processes in which there is some amount of flexibility that allows the system to modify the product or production volume in case of disruptions or shifts in market demand [22]. This flexibility generally involves the following abilities:

- Producing a variety of products on the same equipment and processes
- Producing the same products on a variety of different equipment and processes
- Producing new products on existing machines
- Equipments able to accommodate design changes in the products being manufactured

The two first abilities help mitigate unexpected disturbances and the two latter help facing disruptions caused by new products and designs. Having manufacturing plants able to produce products in multiple ways or with different equipments and processes, allows the transfer of manufacturing demand to another manufacturing process when there are problems with the originally scheduled line [22].

Although initial set-up cost of flexible manufacturing processes is quite high, it has many advantages, such as reducing manufacturing costs in the long term, improved quality and greater machine efficiency, among others. Finally, in contrast to standardized production, flexible manufacturing requires skilled workforce and, when developing new products or changing product requirements, also close communication with suppliers [23].

In a multi-plant environment, that is to say, when a company has various flexible plants available, in case of a disruption, manufacturing can be transferred to another flexible plant in the organization's network. However, in this case, visibility into the capacities and production schedules of the new plant is essential, raw materials requirements need to be adjusted as they have to be delivered to the new plant and transportation must be adapted, as more materials are needed there and the products will be delivered to the customers from there [22].

- ***Employee flexibility***

Employee flexibility is very advantageous for companies in times of crisis. By developing cross – trained employees able to work on different workstations, companies can redeploy employees and production as required in case of disruption or changing demand needs [17].

However, in order for workers to rotate between workstations without disabling other production processes, it is necessary to modify and reschedule the work system, so it can calculate these rotations and possible manners to deal with them. Although having a multi-skilled workforce is expensive, because employees must be trained and the work system must be modified to utilize multi-skilled employees, long term benefits are positive, as flexible employees will enhance the company's resilience [12].

- ***Flexible supply base***

Although sourcing from a single supplier may be advantageous from a cost and quality management perspective, as supply management costs decrease and unit costs become lower thanks to quantity discount, it could be dangerous in terms of resilience. Whilst it may be desirable to have a lead supplier responsible for the supply of a specific item or service, alternative sources should be available whenever possible in order to mitigate the risk associated with sole sourcing [10].

A flexible supply base with multiple suppliers has two main advantages. First, it enables to maintain continuous supply of materials or products when a major disruption occurs, as companies with alternative sources of supply available will have the flexibility to shift production among their suppliers when needed. Second, it enables companies to better handle regular demand fluctuations: if there is more than one supplier, the base volume production can be for instance produced in one plant and the excess of the base volume in another plant [11].

Furthermore, it is highly recommended that one of the main criteria during the selection of suppliers should be their risk awareness. If the supplier has audited its own supply chain risk profile or if he already has procedures in place for the monitoring and mitigation of risk, he will be able to deal more effectively with disruptions [10].

Finally, companies should work closely with their key suppliers to help them improve their supply chain risk management practices, as supply interruptions can have important adverse consequences for all members of the supply chain.

- ***Make – and – buy***

When companies employ make – and – buy strategy, a fraction of their products is produced in-house and the remaining portion of their production is outsourced to other suppliers or contract manufacturers. This strategy increases supply flexibility, as it enables firms to shift production quickly if a disruptive event occurs. Consequently, it increases supply chain resilience [11].

- ***Economic supply incentives***

In some cases, having the flexibility of moving production quickly among different suppliers is not possible due to a lack of available suppliers in the market. In order to gain flexibility, buyers can provide certain economic incentives to cultivate additional suppliers. For instance, companies can share some financial risks with their new suppliers, committing to a minimum order quantity or buying back the unsold stocks at the end of the season at a lower price. They can also assist them with know-how, technical advice and information about the market demand [11].

Moreover, this strategy can also be beneficial even without major disruptions. For example, economic incentives can also be used to entice new suppliers and avoid monopolies. By establishing additional suppliers, firms will be able to keep pressure on suppliers and keep costs low.

In conclusion, economic supply incentives are beneficial for both parties engaging in a contract. The supplier will have the opportunity to diversify in a new business with a minimum order quantity and the customer will be able to maintain the competition for quality and price levels between its suppliers [12].

- ***Flexible transportation***

Transportation plays a key role in supply chain management, as transportation connects all the different nodes of a supply chain and allows materials, parts and products to reach the right place at the right time. Therefore, a failure in transportation could lead to a supply chain breakdown [11].

By incorporating flexibility in transportation operations, a company will enhance its resilience in case of a transport disruption or a need to reroute goods. This flexibility can be achieved thanks to the three following practices:

- Use of multiple transportation modes: To prevent the interruption of supply chain operations in case of a disruption occurs in the ocean, on the road or in the air, some companies use a flexible logistics strategy that relies on multiple modes of transportation. Thanks to this, companies will always be able to choose the optimum transportation mode and satisfy their transportation requirements [11].

- Use of multiple transportation carriers: With multi-carrier transportation, a company will have the flexibility to quickly switch from one carrier to another when needed [12]. In order to ensure continuous flow of materials in the event of political disruptions, such as labor strikes or landing rights, and to achieve low-cost global deliveries, several air cargo companies have formed an alliance called Sky Team Cargo. This

strategic alliance serves as a “safety net” for each carrier, who will receive help from the other members if a disruption strikes [11].

– Use of multiple routes: Having alternative routes can ensure smooth material flows along the supply chains when transportation problems arise. However, in order to be able to adopt multiple routes, the necessary carriers and modes of transportations are required [12].

3.5.1.2. Redundancy

Redundancy entails having extra resources and capacity in the supply chain to enable firms to have a rapid response and recovery from unexpected disruptions [2]. Companies can create redundancies throughout the supply chain by pursuing practices such as holding extra inventory, maintaining facilities or production lines in excess of capacity requirements and committing to contracts for material supply (buying capacity whether it is used or not), among others [17]. A strategic and selective use of redundancy may be fundamental to supply chain resilience [10].

- ***Safety stock***

A company may choose to maintain extra inventory of raw materials, components, parts and finished goods to absorb or cushion the detrimental effect of disruptions and increase the supply chain’s resilience [21]. However, having redundant stocks is a temporary and quite expensive practice that can cause some risks, such as sloppy operations, reduced quality, obsolescence and damage of inventory [6].

First, although it is true that redundant inventory can provide some respite to continue operating after a disruption, this practice is temporary and can only protect the company from a disruption for a few days. If the disruption is longer than anticipated, the stock levels will not be enough for production or satisfying demand [12].

Second, holding extra inventory is often an expensive practice. Companies must pay for having this surplus inventory, which ties up capital and requires management, warehousing, maintenance and prevention of damage [12].

Moreover, redundant stocks inhibit the advantages of lean supply chains. Admired supply chain strategies such as the Toyota Production System[1], the Just – In – Time[2] approach and the Six Sigma Quality[3] aim to create hyper-efficient enterprises that keep inventories and buffer stocks as low as possible in order to deliver high-quality products and offer timely delivery. Nowadays, short product life cycles and the desire to conserve working capital have encouraged many companies to follow these strategies. However, a focus on redundancy

will actually inhibit the companies' ability to achieve such efficiency [18].

Furthermore, as product variety increases and product life cycles shorten, the holding and obsolescence costs of this strategic stock could be exorbitant [11].

Finally, having redundant stocks can contribute to hide manufacturing problems and relax the management discipline regarding the quality of products, because production managers can use the extra inventory to replace a defective part instead of identifying the source of problems [12].

For all the reasons cited above, it is more reasonable to build inventory if the size of disruptions can be estimated with reasonable confidence, in order to calculate the extra amount of inventory needed. Then, this strategy is best applied for items that do not deteriorate quickly and do not require large amounts of money to stock and to maintain them. Further, items selected should also have a low risk of obsolescence, because if not, the strategic stock needs to be renewed regularly so that the items are up to date and suitable for production. Consequently, costs will also significantly increase [12].

On the other hand, instead of having more safety stocks, some firms prefer to store some inventories at certain strategic locations, such as warehouses, distribution centres or logistics hubs, to be shared by multiple supply chain partners. Thanks to these shared inventories, companies can achieve a higher customer service level without incurring high inventory cost when dealing with demand fluctuations or supply chain disruptions [11].

To conclude, keeping an inventory of critical parts and components can be extremely beneficial in the case of demand and supply fluctuations or possible disruptions in the supply chain, as it helps maintain the continuity of the production line. Moreover, although Just – In – Time strategy has proven to be very successful, it is also true that when problems occur, companies have very little stock available, leaving them with less time to react before the impact of problems reaches their customers [24]. However, the extra amount of inventory needs to be carefully calculated and the benefits justified. Last, but not least, the extra inventory should have low holding costs, low risk of obsolescence and deterioration, in order to increase costs as least as possible.

- ***Spare capacity***

Spare capacity is an alternative redundant practice that helps companies deal with disruptive situations. Instead of having safety stock, or in addition to, companies can reserve spare production capacity at their plants and with their suppliers. Examples of spare capacity include extra production lines, alternative manufacturing facilities and extra IT systems, among others [12].

An important distinction between redundancy and flexibility is that redundancy involves capacity prior to the point of need and, consequently, it may or may not be used. In other words, it is an additional capacity that would be used to replace the capacity loss caused by a disruption or in case of a peak demand. However, flexibility entails redeploying previously committed capacity, making readjustments among suppliers, facilities and products [17].

On one hand, companies can build in their plants redundant production lines to produce components for their key products if necessary. This unused capacity will serve them as a cushion to absorb demand uncertainties or disruptions. However, they need to be sure that they have the required employees and inventory to operate this extra capacity. On the other hand, firms can also require their suppliers to provide extra capacity [21].

Although spare capacity can help companies deal with disruptions, it is in fact a costly strategy, as it ties up capital on production facilities that may never have fully utilization rates. With regard to this, the amount of spare capacity is determined depending on the criticality of the product and the lost capital of not having fully utilized capacity. Furthermore, managers will come to depend on this extra capacity instead of trying to implement best practices on the used one [12].

Some companies may choose to use the two redundant practices, capacity and inventory, and others only one of them. The balance between capacity and inventory will depend on the cost of having reserved capacity against the cost of reserving extra inventory. Having excess inventory requires less time than having excess capacity, because changing the inventory levels ordered from suppliers takes less time than changing production levels and training workers. Consequently, building excess capacity usually becomes a strategic choice, as capacity can only be increased or decreased over a period of time [12]. However, if extra inventory is already committed to its final form, instead of a generic or semi-configured form, extra capacity has the advantage of being more flexible than inventory [10].

3.5.2. Collaboration

Traditionally, the nature of relationships between the different players of a supply chain was arms-length, even adversarial. More recently, however, there has been a transformation in the nature of relationships within a supply chain, and a willingness to cooperate and work in partnership has progressively emerged in many supply chains [10].

Due to network nature of supply chains, the management of risk within a supply chain should also be examined from a network perspective. Risk management in a supply chain cannot be properly examined unless a high level of collaboration, cooperation and partnership exists among the different entities [19]. Collaboration occurs when two or more independent companies of the supply chain are actively and effectively working together for mutual

benefits and towards a common objective, in this case dealing with supply chain disruptions [21].

Communicative and cooperative relationships have a positive effect on resilience, as they lead to better risk management and reduce uncertainty by distributing risk [19]. If supply chain entities want to increase their resilience and thus the resilience of the overall supply chain, they must work together with common efforts [6]. Moreover, collaboration and cooperative efforts with supply chain partners are also positively associated with enhancing organizational performance and gaining competitive advantage [21]. There are two main types of collaborative relationships: upstream and downstream the focal firm.

- ***Collaboration with upstream partners***

Early supplier involvement can improve the response time and the cost of suppliers, reduce inventories and reduce the risk of products failure, by managing outcome uncertainty, programming suppliers' tasks, creating common objectives and monitoring suppliers' activities [21].

Maintaining deep and cooperative relationships with suppliers is particularly important when companies rely only on a small group of key suppliers, as each of them is crucial and its failure could have serious consequences for the entire supply chain. By knowing each supplier intimately, a company can, on one hand, better monitor them and be able to detect their possible problems early and, on the other hand, rely on them for help to cope with unexpected circumstances [18]. On the contrary, if a company does not have a close relationship with its suppliers, it will be less informed and, therefore, less forewarned about their potential problems. Consequently, in order to be resilient and responsive to the market, this company should maintain a large supplier network, as having many suppliers distributes the risk in case of a failure occur [18]. In fact, neither of the two strategies above is more correct than the other. The key point is to choose the approach that aligns a company's procurement strategy with its supplier relationships.

- ***Collaboration with downstream partners***

Firstly, exchanging information regularly on downstream inventories and demand conditions with downstream partners can anticipate market trends and demand risks and, consequently, respond quicker to disruptions by rerouting shipments, adjusting capacities or revising the original production plans [9]. Secondly, developing collaborative relationships with customers can increase the visibility of demand and improve planning, which will help reducing uncertainty in demand and, consequently, avoid the surplus or deficiency of products in stock. Moreover, collaborating with clients can also improve customer satisfaction, by correcting problems related to service quality or inefficiencies in transport [25]. For instance,

if a company involves its customers in new product development processes, the company's design team will be able to respond quickly to evolving customer needs and preferences [21].

In order to build collaborative and cooperative relationships between partners, trust and information sharing are essential.

3.5.2.1. Trust

Trust facilitates relationships both within the company and across partners in a supply chain. A trusted network is a network with a certain degree of trust between firms, a high level of cooperation and lower levels of conflicts, as problems and challenges are openly discussed [25]. Moreover, in a trusted network, all partners work actively on their risk management, thus eliminating the risks of the entire supply chain [6]. In other words, trust enhances resilience of supply chains by decreasing supply chain risks.

3.5.2.2. Information sharing

The exchange of information among the different members of a supply chain is a key driver for collaborative working and risk reduction [19].

Although it is true that each member of a supply chain should be able to manage all the uncertainties and risks that arise within its own company, firms also need to efficiently and effectively communicate with one another in order to be able to manage complex and diverse risks. Therefore, investment in information sharing can help identify problems and reduce internal and external risk in the supply chain environment [21]. Companies can achieve more accurate demand forecasting and more efficient coordination by sharing information about demand, supply, inventory, production and purchasing schedules through the Internet, Exchange Data Interfaces[1] (EDI) or Enterprise Resource Planning[2] (ERP) processes [10].

Finally, multiple industry initiatives based on sharing information have been introduced in companies: Collaborative Planning, Forecasting, and Replenishing[3] (CPFR), Vendor-Managed Inventory[4] (VMI) and Efficient Consumer Response[5] (ECR) [21]. These initiatives reduce uncertainty by improving forecasting and planning.

3.5.3. Agility

Nowadays, many companies are at risk because their response times to changes in demand or to supply disruptions are too long [10].

Agility is a key driver of resilience and is defined as the ability of supply chains to rapidly respond to unpredictable changes in demand or supply by adapting their initial stable

[1, 2, 3, 4, 5] *See definitions in the Glossary*

configuration. In other words, agility is related to responsiveness of supply chains in case of disruptions and emergencies [19]. Agility has many dimensions and can refer both to overall networks and to individual firms. Actually, a key to agile response is the existence of agile partners both upstream and downstream the focal company [10].

The two main dimensions of agility are visibility and velocity.

3.5.3.1. Visibility

Supply network visibility can be defined as the knowledge of the status of operating assets and the environment. To put it simply, it is the ability to see one end of the pipeline, from the other end [19]. It implies a clear view of demand and supply conditions, upstream and downstream inventories, production and purchasing schedules.

Total supply chain visibility allows reducing the “bullwhip effect”, which is the amplification of the variation of demand up the supply chain from customer to supplier, and enables supply chain partners to schedule their production more efficiently than just relying on forecasts. But even more importantly, visibility also allows responding more quickly to a disruption and mitigating its effects by making strategic decisions. Thus, visibility is a key factor in supply chain resilience [12].

Thanks to network visibility, companies have information on the form (raw material, subassemblies or finished goods) and location in the supply chain of inventories, as well as information about the capacity and operations of suppliers, manufacturers, logistics providers and distribution networks. In case of a disruption or emergency situation occurs in one part of the supply chain, as supply chain managers know materials and products locations and availability, they will be able to respond more effectively by acting fast and immediately rerouting goods, revising production plans, redeploying production resources and adjusting capacities [24].

The achievement of visibility is based upon close collaboration and cooperation with customers and suppliers, connectivity and information sharing resources. First, collaborative planning with customers enables gaining visibility of demand but also having information about market trends and perceptions of risks. Then, cooperating with suppliers enables gaining upstream visibility and detecting earlier potential supply disruptions [10]. Last but not least, in order to have real-time visibility, companies need information systems that will help them tracking and monitoring their supply chain in real time. The data and information that companies share with their supply chain partners need to be accurate and provide concrete and exact information on the areas affected and the degree of the problem caused. If not, when problems occur, supply chain managers may propose solutions that are not proper as they will not reflect the real situation [12].

3.5.3.2. Velocity

Supply chain velocity is the second key ingredient of agility: in order to be agile, supply chains must be able to react to changes in demand, upwards or downwards, as rapidly as possible. Thanks to velocity, supply chains can recover quicker from a disruption [6].

Velocity means distance over time, and, in a risk event, it determines the loss that happens per unit of time. In order to increase velocity, end-to-end pipeline time must be reduced. In other words, the total time to move materials and products from one side of the supply chain to the other, which means the total time between the placement of an order and the delivery of the product to the final consumer, must be as short as possible [19]. The three basic pillars of improved supply chain velocity are: streamlined processes, that is to say, modernized and simplified processes; lead time reduction and non-value-added time reduction.

Adopting streamlined processes means using processes in which the number of stages or activities involved has been reduced, where activities are performed in parallel rather than in series and e-based rather than paper-based. Moreover, in streamlined processes, order quantities, production batch sizes and shipping quantities are reduced in order to emphasize on flexibility rather than economies of scale. Consequently, streamlined processes enable supply chains to recover quicker from disruptions and provide collateral benefits, such as improved market responses [10].

Then, as supply chains are more vulnerable to disruptions when lead times are long, companies should try to shorten lead times in order to improve the resilience performance of their supply chain [11]. First, in order to reduce inbound lead times, one of the criteria for choosing suppliers and the source of supply should be their ability to respond quickly in terms of delivery and to be able to cope with short-term changes in demand or in the product mix required and to unexpected events. By sharing information with the focal firm and synchronizing schedules, suppliers can become more agile without necessarily having to rely on inventory as a buffer, with all its consequential disadvantages [10]. Companies can also increase their agility by reducing production and transportation lead times [16].

Finally, reducing non-value-added times in the pipeline can help improving supply chain velocity. Non-value-added time refers to all the time spent on activities whose elimination would lead to no reduction of benefit to the customer. In other words, it is the amount of production cycle time that does not directly produce goods or services, the amount of time that goods are not actively being worked on [10]. For instance, moving goods from one department or production area to another, inspection times and waiting times are considered non-value-added times.

3.5.4. Demand management

Firms can also cope with disruptions by implementing some strategies that will enable them to influence or manage the demands of different products. However, these strategies need a good understanding of consumer preferences and how they would respond to price changes and different product offerings [12].

- ***Responsive pricing strategy***

This strategy enables firms to influence the customer production selection dynamically. When a company sells several products and faces a disturbance, it can readjust product's prices or use some kind of special promotion to entice customers to choose products that are widely available instead of the ones whose supply has been disrupted. In other words, by using price or promotions as a response mechanism, companies will be able to shift demand across products when needed and, most importantly, without affecting their customers' satisfaction [16].

- ***Assortment planning***

Retailers can influence consumer product choice and customer demand by reconfiguring the set of products on display, the location of each product on the shelves and the number of facings for each product. This strategy of assortment planning can be used when certain products are facing supply disruptions, as it will help to persuade customers to purchase products that are widely available instead of the products out of stock [11].

- ***Silent product rollover***

The silent product rollover strategy helps companies to handle demand fluctuations or supply disruptions. It consists in introducing slowly and relentlessly new products into the market, without any formal announcement. As a result of this, customers are not fully aware of the particular features of each product, so they are more likely to choose the products that are available rather than the products that are out of stock or being phased out [11]. Thanks to the fact that there are always new products to choose from, customers will not go to the competitors. Moreover, if new merchandise is displayed in limited quantities and during a short period of time, customers will view available products as collectible and more desirable, so they will be motivated to visit shops more frequently [26].

3.5.5. Cultural change

Creating a supply chain risk management culture that makes supply chain risks the concern of everyone within a business is fundamental to achieve resilience along the supply chain.

For the purpose of changing the culture at an organizational level, the role of leaders and top managers is critical: cultural changes cannot be driven without the support and commitment from the leadership. These leaders and top managers should be in charge of reviewing the company policies and practices, in order to determine their impact on the risk profile of the supply chain, and in charge of emphasizing education and training for security and resilience, as employees with knowledge in dealing with uncertainties and changes to the supply chain will be helpful for the company in case of a disruption occurs [10].

Furthermore, supply chain risk assessment should be a formal part of the decision making process at every level. For instance, when designing new products, issues of supply chain vulnerability, such as lead times, component availability or standardization, should be taken into consideration. Likewise, all strategic changes should also be considered in a resilient perspective and the resulting supply chain risk profile should be assessed [10].

Then, a company culture that embraces initiative and motivates employees to respond proactively to situations is essential [12]. To reinforce this idea, teams and individuals at the lowest level in the decision-making process should be empowered to take necessary actions in times of crisis, as they can find out what kinds of decisions need to be made better than anyone in the organization [21]. By distributing power, those that are in the front row, “close to the action”, can take the necessary corrective measures before a potential disruption is even visible to managers. Furthermore, they can respond quickly, which will enable firms to respond to disruptions more effectively and enhance the probabilities of containing the disruption earlier [18].

Moreover, it is essential to keep all the personnel aware of the strategic goals and the business's day to day operations. If employees are continuously informed about the company’s status, and have continuous access to product manufacturing, shipment data and a wide variety of other information, they will be able to use this knowledge to make better decisions when a disruption takes place [18].

Finally, innovation is also a key factor for a company’s long term survival and growth. The level of innovativeness in a company is associated with the culture of learning and participative decision-making. Moreover, innovation is positively associated with supply chain resilience. If companies invest enough in innovation, they will be able to adapt and respond to rapid changes in the environment and, consequently, to overcome disruptions [19].

3.5.6. Security

Last, but not least, in today’s business environment, being resilient is not enough: supply chains also need to be secure. If supply networks do not have comprehensive security processes and procedures in place, the only thing standing between them and a major

disruption is luck [17].

Security refers to the application of policies, procedures and technology to protect supply chain assets (products, facilities, equipment, information and personnel) from theft, damage, terrorism or any kind of disruption [21]. These security initiatives can be classified into the three following groups: (1) “Government initiatives”, (2) “Management strategies” and (3) “Operative routines and technical systems".

1) Governments and businesses have invested in securing logistics and increasing border security. For instance, in response to the terrorist attacks of September 11, 2001, the United States Government established, among others, the following initiatives: the *Container Security Initiative* (CSI) and the *Customs – Trade Partnership Against Terrorism* (C-TPAT) [17]. CSI has the objective to increase security for maritime containers shipped to the United States and is now implemented in almost 60 ports worldwide [27]. C-TPAT is a voluntary, joint government – business partnership to help add security to supply chains and borders and includes nowadays more than 10.000 certified partners. There are many other initiatives: ISO/PAS 28000:2005, which specifies the requirements for a security management system, the Emergency Planning and Community Right-to-Know Act (EPCRA), which improves chemical safety and protects public health and the environment and the Smart and Secure Trade Lanes (SSTL), for securing and facilitating end to end supply chains between Asia and Europe, among others [21].

2) Management strategies refer to strategies implemented by companies and focused on managing supply chain risk and mitigating its negative impact, such as risk sharing contracts, management training and implementation of Total Quality Management[1] (TQM) principles [21].

3) Operative routines involve all the procedures aimed at improving security against adverse disruptions and may include: restricting access to facilities (access control, badges), providing guards for security monitoring, educating employees regarding security issues, conducting inspections, controlling carriers and drivers, screening cargos… Finally, technical systems play an important role in implementing and enhancing security and may include hardware (firewalls, dedicated networks), software (anti-viruses, passwords), camera systems, perimeter alarms, tracking devices and electronic seal systems, among other technical measures [17] [21].

[1] *See definition in the Glossary*

3.6. Challenges

Resilient practices are very beneficial for companies, both under normal circumstances and during disruptions, as they help supply chains to respond to disruptions and recover from them. However, adopting these practices can also create the following challenges.

Firstly, there is a trade-off between the costs of adopting resilient practices on the one hand and the probability and likely impact of a negative event on the other hand [10]. Some firms are not willing to invest in costly strategies for mitigating the negative effects of disruptive events that may not occur and they prefer to opt for passive acceptance of the disruption risk [2]. However, some others are willing to implement these resilient strategies as they value more their benefits, such as preparing them for unexpected events and enhancing the competitive position of their firm especially when their competitors are more vulnerable to disruptions, than their costs [11]. Usually, most of the companies that have refined their supply chain for resilience had actually experienced some type of supply chain disruption in the past [17].

With regard to insurances, only few companies rely nowadays on them to secure their supply chain, for two main reasons. First, insurance premiums for major disruptions, such as terrorist attacks or natural disasters, are extremely expensive. Second, insurances can help companies to stay afloat financially after a disruption, but they cannot protect them from losing their customers' confidence or help them recover their damaged reputation. Damage to a brand can be difficult and expensive to repair; alternatively, building a brand image and reputation takes many years [12].

Second, companies must be careful to choose resilient practices that fit their overall business strategies. For instance, if a retailer follows an "every day low price" strategy, which consists in promising consumers a low price without the need to wait for sale price events, then the resilient practice of responsive pricing strategy is incongruent to the retailer's strategic position in the marketplace [11].

Finally, when a firm opts for a particular resilient practice, it must execute it in a proactive manner, because if not, it will be useless [11].

4. Green supply chains

4.1. Introduction

In the last few decades, industrialization levels have been continuously growing and society has become increasingly aware of the world's environmental problems such as global warming, toxic substance usage and scarcity of natural resources [28]. The increased pressures from community and from environmentally conscious consumers, as well as the rigorous environmental regulations, have forced organizations to integrate environmental concerns into their management practices [5].

Nowadays, one of the main challenges for companies is to manage environmental sustainability along the overall supply chain, since supply chains comprise interdependent organizations, and each of them can influence the reputation and performance of the others. In this challenge, supply chain managers play a key role, as they are in a particularly advantageous position to impact – positively or negatively – the environmental, economic and social performance of their supply chain through the selection and the development of the appropriate green strategies [29].

4.2. Defining green supply chains

Green supply chain management (GSCM) has emerged as a key approach for companies seeking to make their business environmentally sustainable [30]. It implies integrating environmental considerations within the decision-making context of traditional supply chain management and covers all the different stages of a supply chain, from product design, procurement, sourcing and supplier selection, to manufacturing and production processes, logistics, delivery to customers and end-of-life management of products [28]. Its main objective is to eliminate or minimize waste in the form of energy, emissions, hazardous, chemical and solid waste [31].

So, GSCM is a systematic integrated process, from raw material to finished product, aimed at reducing the environmental impacts of supply chain activities, products and services and relieve environmental degradation. However, environmental awareness can also improve productivity and profitability and be a source of competitive advantage [4].

Companies can achieve profit and save costs while improving their ecological efficiency and the one of their partners [28]. As consumers have become more aware of environmental issues, such as environmental degradation and climate change, they have started asking questions about the products and services they are purchasing. Some companies have been

able to convert this public's interest in green issues into increased profits. By implementing environmental improvements in their supply chain, companies can create a more positive corporate image and increase market share. In addition, reducing the environmental impact of the company's processes can also result in cost savings. Improved environmental performance means lower waste disposal, less use of energy and reduced material costs and, consequently, less operational costs.

4.2.1. Green supply chains versus conventional supply chains

Conventional supply chains are focused on economy, ecology is not one of their main objectives. Of course, they may be concerned about their own carbon footprint and may try to reduce the environmental impacts of their products during production and distribution; however, they do not take into consideration their impact on the upstream and downstream part of the supply chain. Finally, there is a limited visibility and collaboration between partners with regard to environmental issues [30].

In contrast, green supply chains integrate environmental criteria and concerns into their planning, management and decision-making and, at the same time, the economic performance, competitiveness and profitability of the overall supply chain must be assured. In other words, for green supply chains, environmental objectives are as important as the financial and operational ones [31].

In a green supply chain, companies consider the environmental effects of all the processes of the supply chain, from extraction of raw materials to the final disposal of products, and not only their individual effects. Each partner provides the necessary information, help and support to the rest of partners, for instance through suppliers' development programs or customer support. Establishing long term relationships is essential to achieve environmental sustainability [30].

Thanks to this visibility and collaboration between partners, the environmental impacts and waste of the overall supply chain will be minimized, while the profits and consumer satisfaction will be maximized [30].

4.2.2. Benefits of green supply chains

By greening their supply chains, companies can enjoy several benefits. The main ones are described below [30]:

- ✓ *Positive impact on financial performance*

Many companies still think, erroneously, that having a green supply chain instead of a

conventional one involves additional expenses. However, it has been proven by both analysis and empirical evidence that, in fact, it is the contrary: adopting greenness has a positive long term net impact on the financial performance of the company.

- ✓ *Sustainability of resources*

Green supply chains promote the effective utilization of all the productive resources needed by an organization. When companies incorporate environmental concerns into their management, they adopt green procurement, environmentally friendly productive processes and green logistics.

- ✓ *Lowered costs and increased efficiency*

One of the main objectives of green supply chain management is improving efficiency by reducing consumption and waste of materials, and by reusing and recycling materials and products. Consequently, operational and production costs will also be reduced.

- ✓ *Product differentiation and competitive advantage*

Supply chains and organizations can gain a competitive edge in the market by being the first to adopt green supply chain practices. By positioning themselves and their products as environmentally friendly, companies will improve their brand image and their brand reputation in customers' minds, which will help attract new customers and keep the existing ones.

- ✓ *Adapting to regulation*

Companies implementing green supply chain practices into their management can reduce the risk of violating environmental regulations and being fined or prosecuted for anti-environmental conduct and unethical practices.

- ✓ *Improved quality and products*

Research and technological advancement allow companies to develop green processes and to identify the areas where environmental degradation can be reduced the most. In other words, green supply chains and technology go hand in hand: environmentally friendly products are also technologically advanced. This will, on one hand, improve quality and products and, on the other hand, strengthen the brand image and reputation of the company in the market.

4.3. Practices for developing green supply chains

As a result of stricter environmental regulations and customers' increasing concern about damage to the environment, environmental issues are becoming part of strategic planning in almost all organizations [32]. Green supply chain management practices can not only help companies to reduce their environmental impact, but also to optimize their end-to-end operations to achieve greater cost savings and profitability. According to the literature, several green practices have proven to be successful. In this chapter, the most representative ones will be described in detail.

Green practices can be classified in the three following levels, represented in Figure 4:

1) *From suppliers to the focal company*
2) *Intern to the focal company*
3) *From the focal company to customers*

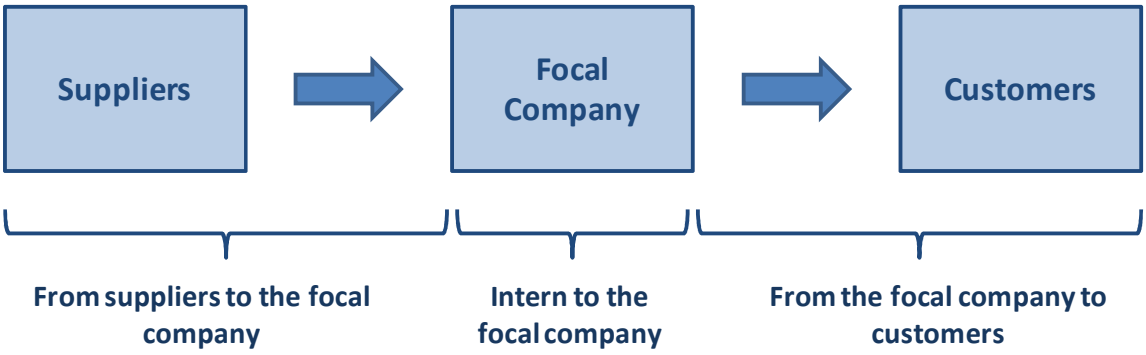

Figure 4: Classification of green practices

4.3.1. From suppliers to the focal company

This first category refers to green practices developed in the upstream portion of the supply chain and associated with environmental interactions between a company and its suppliers. It includes green procurement and evaluation of suppliers' environmental performance.

- ***Certification of supplier's Environmental Management Systems (EMS)***

Environmental Management Systems (EMS) have been developed as tools to allow the management of companies or organizations to better identify, manage and control their activities that can impact the environment [33]. The main objective of these systems is to

ensure an improvement in the companies' environmental performance, especially with regard to natural resources, polluting air emissions, water consumption and discharges, soil and noise levels [34]. Implementing EMS not only benefits the environment by ensuring that environmental issues are integrated into the management of the company, it also reduces costs and improves efficiency within the organization. However, nowadays, there is no legal obligation for organizations to implement EMS, it is voluntary.

Although there is a wide range of EMS certification standards, the international standard series ISO 14001 is the most frequently applied. This standard specifies the requirements of EMS and provides guidelines and frameworks that will help organizations to improve their environmental management efforts. ISO 14001 standards are process, not performance, standards. In other words, they do not tell organizations what environmental performance they must achieve but rather focus on the system that should be put in place to help an organization achieve its environmental objectives [35].

The environmental sustainability along the overall supply chain depends on the environmental reputation of each of its members. In other words, if suppliers do not measure and try to improve their environmental impacts, then they will also negatively affect the environmental performance of buyers [29]. For this reason, companies are increasingly requiring their suppliers to have certified EMS. Thanks to this, they will make sure that their suppliers take into consideration environmental management, which will improve the overall greenness of the supply chain.

The certification of EMS must be done by an independent and accredited body, which will attest if the supplier's system complies with all the requirements of ISO 14001.

- ***Environmental collaboration with suppliers***

Due to increasing concern for environmental issues and regulations, companies are continuously looking for practices and relationships for sustainable growth. By including environmental concerns into their relationships with their suppliers, companies can reduce the overall environmental impact of their supply chain. Among the reasons for this increasing interest in environmental collaboration with suppliers is that the environmental impact of the product throughout its life cycle cannot be reduced without considering the contribution of the preceding stages of the supply chain [36].

Environmental collaboration with suppliers means that the company works closely with its suppliers, they become partners. They leverage each other's resources, provide guidance, advice and assistance and share their knowledge and skills. For instance, they can work together to improve the product design and manufacturing processes or to improve the overall compliance with environmental regulations. Thanks to this collaboration, they will

implement modifications that will lead to pollution prevention, lower material and energy usage and lower waste and waste treatment cost. These environmental improvements will in turn contribute to business performance for both parties [36].

However, environmental collaboration with suppliers requires an investment of time and resources for both parties, and its result depends on the suppliers' characteristics and the ability to induce environmental process improvements [32].

- ***Environmental monitoring of suppliers***

Companies can perform continuous auditing and monitoring of the environmental impact of the activities carried out by their suppliers [5]. Generally, the results of this environmental monitoring are compiled in tracking reports that contain, on one hand, information about the supplier's environmental performance and, on the other hand, the corrective, preventive and improvement actions and programs proposed.

The main purpose of this practice is not only tracking the suppliers' behavior and their compliance with environmental regulations, but also establishing regular contact with them, raising awareness, increasing transparency and, most importantly, highlighting the problems that need to be rectified and providing them with support in environmental matters so as to continuously improve their environmental management and performance [36].

Although the cost of an effective environmental audit may put off some companies, the benefits in the long term will usually make the cost worthwhile, as environmental monitoring of suppliers enhances their environmental performance and, consequently, also the one of the overall supply chain [36].

- ***Green procurement***

Green procurement seeks to reduce the company's environmental impact related to the sourcing of materials, products and services. Companies aim to buy materials and products whose environmental impact is lower than the equivalent market average, considering all phases of the life cycle, in particular end-of-life management [37]. Obviously, the most important feature of green sourcing is considering if the purchase needs to be made at all and, if it does, ensuring that quantities are accurate and that there is little wastage.

Although the green procurement process depends on the type of product or service required, generally, it involves looking at some of the following aspects (non-exhaustive list) [37]:

- Manufacturing process: Quantity of water and energy used during the process, compliance of the factory with relevant legislation, product's lifespan.

- Materials: Origin, composition, presence of chemicals, type of packaging.
- Transportation: Provenance of the product and kilometers travelled to reach the company, possibility of calculating the carbon footprint, capacity of trucks used.
- Waste management: Legal obligation for safe disposal, hazardous product or not, possibility of being re-used or recycled (both the item and its packaging).

Companies can ask their suppliers to adhere to certain environmental criteria before buying a product or a service or signing a contract. Therefore, green procurement promotes closer working relations between suppliers and buyers.

A common misconception is that green sourcing is expensive. However, it can bring long-term costs benefits, as companies will be able to reduce resource consumption and waste generation and to improve efficiency in removing waste products. In addition to these economic benefits, green sourcing has many non-economic advantages, such as reducing environmental costs, creating a positive image in the minds of customers and improving reputation in the market [38].

4.3.2. Intern to the focal company

This second category concerns all the green practices developed by a company in its daily and internal operations.

- ***ISO 14001 certification***

By completing ISO 14001 certification, the focal company assure stakeholders that its Environmental Management System (EMS) meets international environmental standards.

Having a certified EMS provides the following benefits, among others [34]:

- Management of environmental risks
- Quantifying, monitoring and controlling the impact of operations on the environment
- Compliance with environmental regulations
- Costs savings in resource, waste and energy management
- Improving the environmental performance of the entire supply chain
- Improving the corporate image
- Advantage over competitors when tendering for business
- Can reduce public liability insurance costs
- Can influence the rest of supply chain partners to adopt more environmentally friendly practices

- ***Using environmentally friendly raw materials***

Growing concerns over environmental degradation and exhaustion of natural resources caused by economic growth suggest that firms may need to rethink their procurement strategies. While some companies have not changed their behavior, many companies have begun to make changes in the ways they gather raw materials for their products [39].

By using environmentally friendly materials, or eco-materials, companies can decrease their impact on environment. Eco-materials are defined as those materials that contribute to reduction of environmental burden throughout their whole life cycle and that satisfy at least one of these six conditions [40]:

- Green resource profile: Provenance from green resources. In other words, the use of non-renewable and renewable resources should be reduced, the use of recycled resources should be increased and non-renewable resources should be substituted by well-managed renewable natural resources.
- Production process of minimal environmental impacts: Minimization of environmental impacts of materials during material and product manufacturing, recycling and waste disposal. Major issues in this aspect are: reducing CO_2 and pollutants emissions, reducing energy and input materials, increasing production yield, saving landfill area.
- High productivity in use: This aspect entails reducing energy and input material at consumption stage and enhancing reuse and longevity of materials and products.
- Minimal hazardous substance: Reduction of the emission of hazardous chemical substances from the product and waste.
- High recyclability: Contribution to efficiency recycling. Major issues in this aspect are, among others, if the material increases ratio of recycled resources and if the material enhances separation and recovery ability of other products.
- High environmental treatment efficiency: Increase of the efficiency of environmental treatment or purification processes, such as purifying volatile organic compounds or removing hazardous substances in the environments.

- ***Reducing energy consumption***

Over the last years, energy efficiency has received increasing attention due to the environmental and economic impacts associated with the consumption of energy. For instance, one of the objectives of the European Commission is to reduce the annual consumption of primary energy by 20% by 2020 [41].

The environmental performance throughout the overall supply chain could be improve by investing in new technologies and implementing more efficient processes that reduce energy consumption. From the manufacturing companies' point of view, there are several drivers to reduce energy consumption and introduce energy efficiency improvements [41]:

- Saving costs: The cost of energy is one of the most important factors in the overall costs of production processes. Moreover, energy prices are rising.
- Reducing CO_2 emissions: Carbon dioxide emissions resulting from the combustion of fossil fuels represent the largest source of greenhouse gas emissions generated by human activity. Consequently, reducing energy consumption, as well as trying to replace fossil fuels with renewable energies, contributes to the reduction of greenhouse gas emissions, thereby helping to combat climate change. In addition, in the last few years, new environmental regulations with their associated costs for CO_2 emissions have been implemented.
- Improving competitiveness: Reducing the amount of energy consumed in the generation of final products and services obtained improves the competitiveness of the company.
- Improving the corporate image and increasing market share: Customers are increasingly aware of and concerned about environmental issues, and they are changing their purchasing behaviour with regard to "green" and energy efficient products and services.
- Strengthening technological innovation: The search for energy efficiency is closely linked to innovation.
- Improving the performance of production equipment: Increasing control, monitoring and maintenance of production equipment, besides reducing energy consumption, promotes the improvement of the production process.

- ***Minimizing waste***

Waste minimization is a key element in green supply chains as it helps conserving resources, preventing pollution and reducing costs. In order to reduce waste in a supply chain, several strategies can be implemented [42].

Firstly, waste reduction begins with product design. Companies can examine the design of their products in order to identify in which parts the use of raw materials could be decreased. Regarding product packaging options, firms can examine cheaper and less wasteful materials.

Secondly, each production process should be examined and, if necessary, redesigned in order to minimize the waste of raw materials and to eliminate the presence of waste material that cannot be recycled or reused. Manufacturing processes that produce waste that can be recycled should also be examined, as recycling costs are quite expensive and it is preferable to expand the presence of waste material that can be reused rather than recycled.

Finally, companies should also improve the overall quality of their manufacturing processes, as it will increase the quantity of finished goods that pass quality controls and inspections and, consequently, it will also reduce waste.

- ***Reusing and recycling materials and packaging***

With the increasing demand for manufactured goods and the decreasing availability of landfill space, reusing and recycling is becoming more a necessity rather than a green and good idea. Reusing means using the product again, with or without any alteration, and recycling is defined as the collection of end-of-life or faulty products in order to use them again, in the same form or in a different form [30].

By reusing and recycling materials and packaging, companies become more responsible ecologically by reducing waste, reducing energy usage, preventing air and water pollution, saving natural resources and avoiding producing unnecessary products. In terms of economic savings, businesses can lower their costs thanks to this practice: first, reusing and recycling can reduce operational costs, as it helps reducing storage, and can reduce production costs, as the cost of reusing material or using recycled material is much lower than the one of creating new material with which to work. Moreover, when recycling is implemented on a large scale, the savings that can be made become hugely significant. Finally, it enables cultivating a green image and increasing the attractiveness of the company, both internally (to employees) and externally (to supply chain partners or external parties) [30].

However, the reuse and recycling requires high levels of collaboration and cooperation along the supply chain [5].

- ***Design products for disassembly***

Over the last years, designing for disassembly has increased in popularity among the manufacturing companies. Design products for disassembly is a design strategy that takes into consideration the future need to disassemble a product in order to be repaired, re-used, remanufactured, refurbished or recycled. The disassembly must be easy, because if not, the cost of disassembly will probably be much larger than the revenue obtained from recycling the parts and materials of the product [30].

In design for disassembly, there are two levels of strategy: product disassembly, which means breaking products down in order to reuse their components, and material disassembly, which refers to the action of breaking down a product for reusing its materials instead of its individual components [43].

The main advantages of designing products for disassembly are reducing costs, as it facilitates maintenance, repair and re-use of parts, components or materials, reducing waste disposal, as parts with no defects are reintroduced in the supply chain and put back into production instead of being disposed, and increasing product quality, as the individual parts, instead of the whole product, are tested for quality and durability, which enhances the quality of the overall product [43].

- ***Decreasing inventory levels***

Having too much items that will not be sold represents both an economic and an environmental cost. On one hand, excess inventory in warehouses costs money as it ties up capital and requires management, warehousing, maintenance and prevention of damage and theft. On the other hand, it also represents an environmental impact, as in order to produce this inventory stock, it has been necessary to use materials, carbon and water [42].

So, managing inventory well is both a financial win and a sustainability victory, as it will enable companies to save resources and a lot of money in manufacturing, distribution and warehousing. However, it is a challenging task, due to uncertainty of demand, increasing pressure to maintain continuity of supply, increasing customers' expectations, shorter product life cycles and increasing risk of supply shortages due to supply chain complexity, among others [44].

- ***Cross-functional cooperation for environmental improvements***

Due to the increasing customers' demand for more sustainable products and services, the need to comply with laws and regulations and the different stakeholders' requirements, companies began to integrate environmental considerations into their management. Environmental issues are relevant since they can be related to risks, as not taking into account environmental issues can damage the company's reputation, or, on the contrary, to opportunities, as companies that invest in eco-innovation and develop environmentally sustainable products and processes can improve their corporate image and increase their market share. As a consequence, in many organizations, the different functional units started to work together in order to improve the environmental sustainability of the overall supply chain [45].

Cross functional cooperation occurs when employees from different departments, disciplines

and functions work in unison towards the same objective [46]. As stated previously, green supply chain management is not just an issue that affects procurement; it also affects other departments such as research and development (R&D), design, marketing or production. For instance, when a new environmentally friendly product has to be developed, the different departments need to work together in order to know about the demanded properties of the new product and share ideas about what is commercially important, technically feasible or difficult to manufacture. Cross functional cooperation has demonstrated being a critical success factor for new product development and is particularly crucial when the new product is characterized by high levels of market risks or technological advancement and. Another example is waste reduction, which is an environmental matter that not only involves the purchasing department, but also the one of human resources, since the employees should be trained in order to know how to avoid waste in the most efficient and effective way [45].

Both formal and informal communication is essential in cross functional cooperation. Formal communication is useful for transferring explicit knowledge across the internal supply chain and informal communication can be of help to establish a common language across the different functional units. By communicating appropriately since the beginning, rumors and misinformation can be avoided. Moreover, it will help to raise awareness of the team's objectives and build relationships between members [45].

However, if the members of the cross functional team come from different backgrounds, the level of conflicts may be increased. But, as long as the members overcome these barriers, projects can be successful [46].

Last, but not least, the objectives of the project must be clear for all the members of the cross functional team, as this will help the whole project to stay on target. Moreover, departmental goals should be aligned with cross-functional team goals, because members will be more willing to cooperate and this will improve the likelihood of success [46].

4.3.3. From the focal company to customers

This third and last category involves practices deployed in the downstream part of the supply chain and concerning all the interactions between a company and its downstream partners (distributors, retailers…).

- ***Environmental collaboration with customers***

Companies can improve their environmental performance by implementing cooperation and collaboration with end customers.

Companies can engage environmental activities and awareness programs with their

customers to improve the sustainability of their production processes, to reduce the environmental impact of their products, to develop a mutual understanding of responsibilities regarding performance and to solve environmental-related problems [5]. As customers are the ones who use the products and services of a company, their feedback is particularly valuable when it comes to improving sustainability [30].

- ***Green packaging***

Packaging is probably the most visible element in an environmentally sustainable supply chain and can have a considerable impact on the environmental performance of the overall supply chain. Thanks to green packaging, companies can both reduce costs and reduce environmental impacts.

The four main differentiators between traditional packaging and green packaging are [30]:

- Reduce packaging: Many end consumers believe that companies are doing an overuse of packaging. The most environmentally proactive customers are asking companies to reduce the packaging of their products to its bare minimum, in order to reduce environmental impacts.

- Reuse packaging: In some cases, companies take back the packaging from their customers and put it back in reuse in a closed loop chain. This strategy is particularly relevant for products that are directly delivered to customer premises, because the delivery personnel can take back the packaging after the delivery almost without additional cost and the packaging has no other function than the safety in transit and in storage. For instance, this strategy can be done with products for industrial customers, furniture, household appliances…

- Recycle packaging: Many times companies cannot collect and reuse the packaging, due to its nature or the type of transaction. In that case, the packaging should be recycled. Recycling programs are nowadays operating in almost all the countries and companies can also collaborate by providing information to their customers about the recycle chain.

- Reform packaging: This strategy includes producing packaging with biodegradable material, changing to more environmentally friendly materials, changing the method of delivery… It is the most innovative strategy, and the one that requires the most advanced technologies.

- ***Reverse logistics***

Initially, the growing attention on reverse logistics issues was originated with public awareness. But then, governmental legislations started to obligate manufacturers to take care of their End of Life (EOL) products. For example, the first Waste Electrical and Electronic Equipment (WEEE) Directive of the European Union entered into force in 2003, and required manufacturers to take back from consumers all types of electric goods and ensure their environmentally sound disposal. After Europe, similar legislation was also introduced in Canada, Japan, China, and many states in the United States [4].

The concept of reverse logistics has been subject to many definitions and much debate. Generally, reverse logistics is defined as the process of planning, implementing and controlling the efficient and cost effective flow of products once they have been used and have ceased to function, from the point of consumption to the original point of manufacture, for the purpose of recapturing value or proper disposal. Collected products from customers can be recycled (to have more raw materials or raw parts), remanufactured (to resell them to second markets or if possible to first customers), repaired (to resell them to second markets) or disposed of [47]. Some definitions also include in reverse logistics the return of packaging or the return by consumers of faulty products [48].

So, thanks to reverse logistics, companies can minimize environmental impacts, improve customers' satisfaction, save costs and recover lost profits by reusing or reselling materials.

5. Description of the Ecosilient Index

5.1. Introduction

As stated in the previous chapters, resilient and green paradigms are in the ascendancy in the field of supply chain management. However, despite their importance, there is still not a proper way to measure the levels of resilience and greenness in supply chains. For this reason, the authors S. G. Azevedo, K. Govindan, H. Carvalho and V. Cruz – Machado have created the Ecosilient Index.

The Ecosilient Index is an integrated assessment model aimed at evaluating the level of resilience and greenness of automotive companies and their corresponding supply chain.

As supply chains are composed of several companies, each of them with a different degree of resilience and greenness, the overall behaviour of supply chains will directly depend on the aggregation of individual companies' behaviours. Therefore, it is first necessary to determine the Ecosilient Index for all the individual companies belonging to the supply chain under study and, then, the Ecosilient Index for the overall supply chain.

5.2. Ecosilient Index for individual companies

The Ecosilient Index of an individual company is calculated from its resilient and green behaviours:

- Resilient Behaviour (B_R): This indicator expresses the degree of resilience of a company and is calculated from the level of compliance of a set of Resilient Practices (P_R) implemented by the company. These practices reflect the company's ability to deal with unexpected disturbances.

- Green Behaviour (B_G): This indicator represents the degree of greenness of a company and is obtained from the level of compliance of a set of Green Practices (P_G) implemented by the company. The main objective of these practices is to improve the company ecological efficiency.

Both Resilient Practices (P_R) and Green Practices (P_G) are sub-indicators assessed on a five point Likert scale, where 1 means "practice not implemented" and 5 means "practice totally implemented".

The authors have chosen for the automotive sector a total of 7 Resilient Practices (P_R) and 7 Green Practices (P_G), which are described in Table 1 and in Table 2.

Resilient Practices (P_R)	Description
Sourcing strategies to allow switching of suppliers	The ability to switch suppliers quickly can help companies to recover from a disruptive event.
Flexible supply base / Flexible sourcing	It consists of having a range of options available and the ability to effectively exploit them, in order to be able to respond to changing requirements related to the supply of purchased components.
Strategic stock	Holding some inventories at certain “strategic” locations and sharing them with other supply chain partners can be useful in case of a disruption [10].
Lead time reduction	Supply chains with long lead times are more vulnerable to disruptions.
Creating total supply chain visibility	A clear picture of inventories and flows in the supply chain, the logistic network as well the status of vendors, manufacturers, intermediaries and customers, is essential for effective management.
Flexible transportation	Having multi-modal transportation, multi-carrier transportation and multiple routes can ensure continuity of materials and products flows even when a transportation disruption occurs [11].
Coordination with downstream partners	Supply chain partners who exchange information regularly on downstream inventories and demand conditions can anticipate market trends and demand risks and, consequently, respond quicker to disruptions by rerouting shipments, adjusting capacities and / or revising the original production plans [10].

Table 1: Resilient Practices (P_R)

Green Practices (P_G)	Description
Environmental collaboration with suppliers	Interactions between organizations and suppliers in order to improve the environmental performance of the supply chain: sharing knowledge, implementing environmental programs...
Environmental monitoring of suppliers	Continuous auditing and monitoring of the suppliers' environmental performance, to determine if they comply with environmental regulations and if the improvement measures implemented are contributing to their performance.
ISO 14001 Certification	It defines the criteria for an Environmental Management System (EMS) requiring commitment to compliance with applicable legislation, regulations and continuous improvement.
To reduce energy consumption	It consists of improving the environmental supply chain performance with more efficient processes that reduce energy consumption.
To reuse/recycling materials and packaging	The reuse and recycling of materials and packaging results in operational costs savings and in a reduction in environmental impact. Cooperation with suppliers is required.
Environmental collaboration with the customer	It consists of developing a series of environmental activities involving clients aimed at reducing the environmental impact of the company and solving environmental – related problems.
Reverse logistics	It involves all the activities associated with the collection and either recovery or disposal of used products.

Table 2: Green Practices (P_G)

For each company, the two indicators Resilient Behaviour (B_R) and Green Behaviour (B_G) can be calculated aggregating the correspondent individual sub-indicators, that is, Resilient Practices (P_R) and Green Practices (P_G), according to their importance or weight.

So, for each individual company j, the following formula is used to compute each indicator B_X according to the paradigm x, where x is "R" (for resilient behaviour) or "G" (for green behaviour):

$$(B_x)_j = \sum_{i=1}^{7} w_{xi} * (P_{xi})_j$$

Subject to:

$$\sum_{i=1}^{7} w_{xi} = 1$$

Where:

- $(B_x)_j$ represents the resilient (when x = R) or green (when x = G) behaviour of the individual company j of the supply chain concerned.
- $(P_{xi})_j$, with $i = 1, \dots, 7$, is the implementation level of practice i of paradigm x for the individual company j. A total of 7 practices are considered for each paradigm (see Tables 1 and 2). As stated before, the implementation level means the level of compliance of each practice in the company, and is assessed in a five point Likert scale from 1 to 5, where 1 is "practice not implemented" and 5 is "practice totally implemented".
- w_{xi} , with $i = 1, \dots, 7$, represents the weight of practice i of paradigm x. This weight is common for all the companies that belong to the same supply chain.

In other words, the company behaviour according to a resilient or green paradigm is calculated applying additive weighting of each practice implementation level. For each company, the behaviour B_x will also range from 1 (no resilient or green practices implemented) to 5 (all the 14 practices are totally implemented), as the sum of the weights is equal to 1 for each paradigm.

The Ecosilient Index for a particular individual company, $Ecosilient_j$, can be calculated applying the following formula:

$$Ecosilient_j = w_R * (B_R)_j + w_G * (B_G)_j$$

Subject to:

$$w_R + w_G = 1$$

Where:

- $(B_R)_j$ represents the resilient behaviour of the individual company j and $(B_G)_j$ its green behaviour.
- w_R and w_G represent, respectively, the weight of resilient and green paradigms. These weights reflect the importance of each paradigm for the supply chain competitiveness.

The hierarchical relationships involved in the Ecosilient Index for individual companies are shown in the Figure 5.

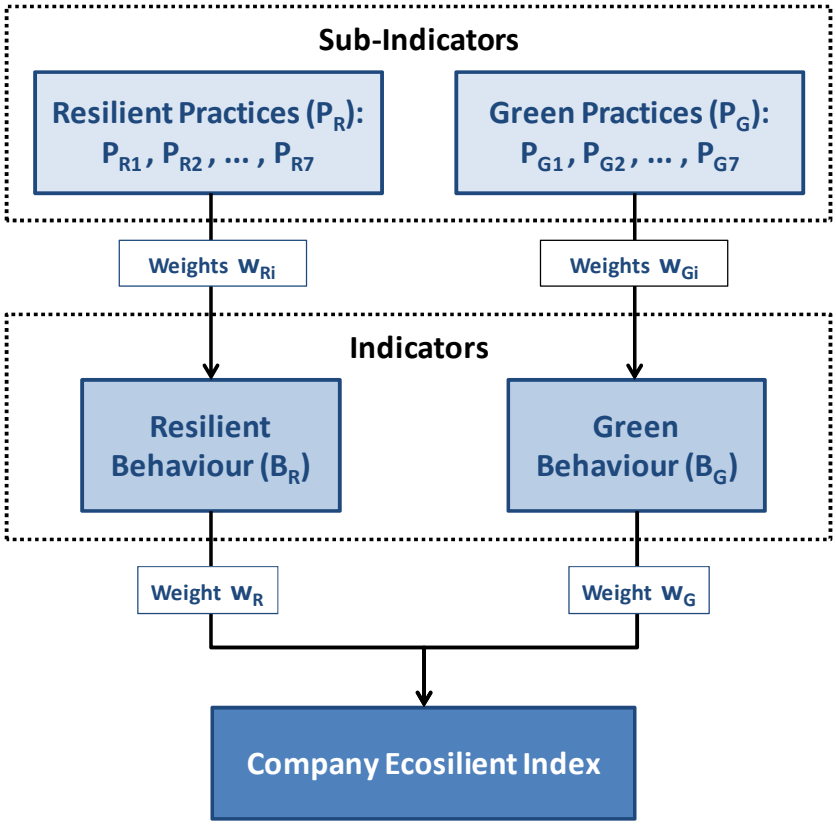

Figure 5: Hierarchical relationships involved in the company Ecosilient Index

Finally, the authors use the Delphi technique to determine the weights of the supply chain paradigms and their corresponding practices.

This technique is a highly formalized method of communication and consists in asking a

group of experts their opinions on a specific issue. This group of experts answers questionnaires in successive rounds, anonymously, in order to try to achieve consensus, but with utmost autonomy and independence from the rest of experts. The Delphi method has been used in several other studies to determine indices in a supply chain context.

For the Ecosilient Index, the authors have used a panel of eleven experts, and three successive rounds of Delphi questionnaires.

5.3. Ecosilient Index for the overall supply chain

As supply chains are constituted by several companies, in order to obtain a supply chain indicator according to each paradigm, resilient or green, the individual companies' green and resilient behaviours must be aggregated.

The supply chain indicator according to the paradigm x, SCI_x, where x is "R" (for resilient behaviour) or "G" (for green behaviour) represents the resilient or green behaviour of the overall supply chain, and can be calculated applying the following formula:

$$SCI_x = \frac{\sum_{j=1}^{n} (B_x)_j}{n}$$

Where:

- n is the number of companies that belong to the studied supply chain
- $(B_x)_j$ represents the behaviour of the individual company j according to the resilient (when x = R) or green (when x = G) paradigm.

The Ecosilient Index for a particular supply chain, $Ecosilient_{SC}$, is calculated aggregating the supply chain indicator of each paradigm, resilient and green, with their corresponding weights. The following formula is used:

$$Ecosilient_{SC} = w_R * SCI_R + w_G * SCI_G$$

Subject to:

$$w_R + w_G = 1$$

Where:

- SCI_R represents the resilient behaviour of the supply chain considered and SCI_G its green behaviour.

- w_R and w_G represent, respectively, the weight of resilient and green paradigms. These weights are the same than the ones used in the Ecosilient Index for individual companies.

The supply chain Ecosilient Index also goes from 1 (no paradigm put into practice in the supply chain firms) to 5 (both paradigms are completely deployed in the supply chain firms).

Finally, the hierarchical relationships of the supply chain Ecosilient Index are showed in the Figure 6.

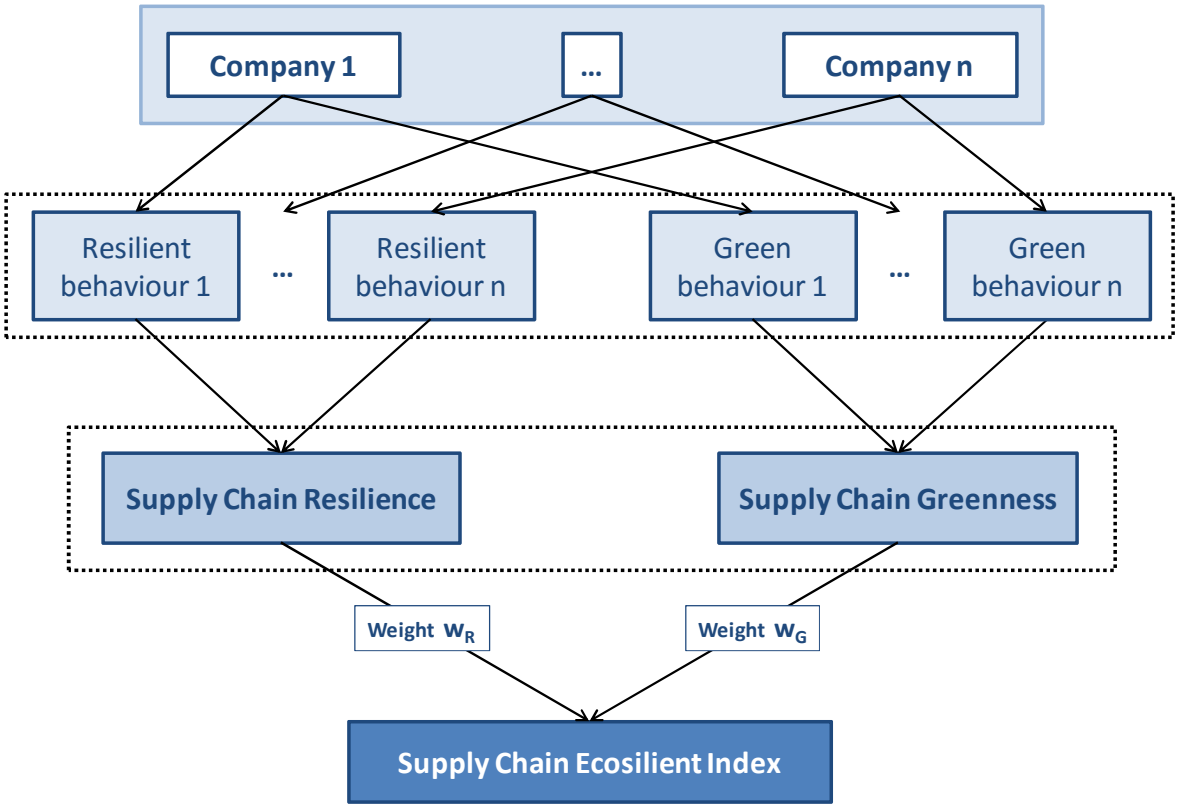

Figure 6: Hierarchical relationships involved in the supply chain Ecosilient Index

6. Improving the Ecosilient Index

The present chapter includes some proposals for improving the Ecosilient Index for automotive supply chains.

6.1. Proposal of additional resilient practices

6.1.1. Overview of the automotive sector with regard to resilience

In recent years, the automotive industry has suffered many blows that have severely affected its revenues and profits. On one hand, the Great Recession and the slow economic recovery worldwide affected demand and, on the other hand, many terrorist attacks and natural hazards, such as floods, earthquakes or tsunamis, have severely damaged sourcing, production and delivery activities of car manufacturers for an extended time [49].

For instance, in 2011, the Fukushima tsunami and nuclear meltdown in Japan perturbed many international supply chains, mainly in the automotive sector. This natural disaster affected Toyota's suppliers, including the Japanese semiconductor manufacturer Renesas, responsible of about 40 per cent of the production of Toyota's chips. As Renesas only had one factory in Japan, when that factory was devastated by the tsunami, Toyota had to shut down manufacturing all over the world, making the company lose nearly 3.5 billion dollars and its position as the world's top automotive manufacturer. General Motors faced a similar kind of supply chain exposure. However, as it had built sufficient redundancy into its supply chain, it was able to ensure continued manufacturing of its most profitable vehicles by reconfiguring its supply chain. Thanks to this, the tsunami did not have impact on General Motor's earnings [50].

All these events and the implications they had on automotive supply chains served as a wakeup call for many companies.

Supply chain risk has been an unintended consequence of globalization and lean production, the two most significant trends in recent decades [24]. As inventor of the lean production philosophy, originally known as the Toyota Production system, the automotive industry strictly adheres to the principles of JIT delivery and low inventories. Thanks to lean production, which most important purpose is increasing productivity and reducing costs and resources by eliminating all kinds of unnecessary functions in the factories, mass production became more efficient [51]. However, lean and efficient supply chains face higher risks of disruptions. At the same time, the development of global vehicle platforms has extended some of those lean supply chains over great distances, making them more vulnerable to

transportation disruptions and to natural disasters [24].

So, to put it simply, traditional lean automotive supply chains were highly susceptible to disruptions. As production line stoppages can be as high as 100.000 dollars per minute in the automotive sector, car manufacturers started to revise the conventional lean model and to define and implement supply chain resiliency strategies that could protect them against failure. By building hybrid supply chains that are simultaneously resilient and lean, car makers are able to cope with disturbances, thanks to flexible practices and controlled redundancy, while preserving and enhance profitability, as the principles of Just – In – Time and lean manufacturing are retained [50].

The automotive sector is under heavy cost pressure and, to be more competitive, companies must reduce logistics costs as much as possible and improve market share. Building this hybrid supply chain that is both lean and resilient is not an easy task, as the need to reduce costs must be balanced with the implementation of redundancy, flexibility, agility and other resilient practices. The solutions depend on multiple variables, such as geography, providers and customers. Moreover, this kind of hybrid supply chain is still in its early stages. However, there are some attributes that coincide in most hybrid supply chains [50].

First, as the automotive industry focuses on lean production, car manufacturers prioritize supply chain agility and production flexibility over buffer stocks and redundant capacity, which can be inefficient [52]. To mitigate the impact of supply disruptions, the automotive sector can implement flexible sourcing, increase flexibility inside assembly plants and use multimodal transportation solutions to balance speed and cost. In case of a disruption, affected parts can be switched temporarily to another transport mode, preferably faster, to keep assembly lines supplied until normal service begins again [24].

With regard to redundancy, instead of carrying more safety stocks, automotive companies can store some inventories at certain strategic points, to be shared by multiple supply chain partners. For instance, Toyota keeps inventories of cars and appliances at certain strategic locations so that all retailers in the nearby region share these inventories. Thanks to this, Toyota can deal with regular demand fluctuations or unexpected disruptions and achieve a higher customer level, without incurring high inventory cost [11]. However, generally, car manufacturers do not apply redundant capacity, as many carmakers suffered overcapacity problems during the recession of 2008 [24].

Then, as risk management must be collective rather than sequential, cooperation, collaboration and information sharing between supply chain partners is essential in order to achieve resilient automotive supply chains. In other words, resilient supply chain management is based on collaborative partnerships. The essence of these partnerships is, for all parties, to mutually benefit from working together. For instance, partners can develop

together innovative continuous improvement plans. These partnerships should span all players in the sector: suppliers, original equipment manufacturers and supply chain service providers, among others.

Last, but not least, supply chain resiliency is impossible without real-time and multi-tier visibility. Visibility reduces uncertainty, enables companies to achieve a demand-driven supply chain and reduces supply chain risk through shared information, both upstream and downstream of operations. In order to have accurate and real time information about supplier production, inventories and in-transit goods, the supply chain must be tracked and monitored continuously [50].

In conclusion, lean and resilient automotive supply chains should have agility, flexible production, appropriate redundancy, collaborative partnerships, end-to-end supply chain visibility, flexible transportation and delivery and supply chain risk management culture, among others.

6.1.2. Additional resilient practices suggested

In addition to the practices proposed in the Ecosilient Index, after the review of the literature in Chapter 3 and the previous overview of the automotive sector regarding resilience, the two following practices are suggested.

6.1.2.1. Cooperation with upstream partners

One of the most important features of automotive supply chains is that there are numerous sorts of raw materials and the manufacturing process of vehicles needs a lot of different components [2]. However, the number of available suppliers for components and parts is quite reduced [5]. Moreover, as mentioned in the previous section, a single missing component can stop a production line and provoke economic losses from 10.000 to 100.000 dollars per minute. Consequently, supply chains are very vulnerable to non-delivery of components and parts [24].

For these reasons, the automotive industry is willing to invest in risk management strategies related to the continuous supply of components and parts. The Ecosilient Index already includes some practices related to this, such as flexible supply base, ability of switching supply base, flexible transportation and strategic stock [5]. However, it would also be necessary to include cooperation with upstream partners, as collaboration and information sharing between the focal firm and its suppliers is essential in order to achieve resilient automotive supply chains, especially when the focal firm relies on a small group of key suppliers.

As stated in Chapter 3, when companies depend on few suppliers, it is essential to have a deep relationship with all of them, as they are crucial and their failure could have serious consequences for the overall supply chain. By developing a collaborative partnership with each supplier, the focal firm can, on one hand, better monitor them and be able to detect their possible problems early and, on the other hand, rely on them for help to cope with unexpected events. For instance, in 1997, the automotive company Toyota was able to recover quickly when the only plant of its main supplier of P-valves was burnt down, thanks to the loyalty and help of the rest of its suppliers [18].

6.1.2.2. Flexible manufacturing

As the automotive industry focuses on lean production, car manufacturers prioritize supply chain flexibility rather than redundancy when it comes to resilient practices. This is due to the fact that supply chain strategies such as Toyota production System and Just – In – Time create hyper-efficient enterprises that keep inventories and buffer stocks as low as possible and a focus on redundancy will inhibit such efficiency [18].

Adopting a more flexible manufacturing strategy could help automotive companies to cope with disturbances [2]. Flexible manufacturing is, in its essence, the ability to produce different vehicles on the same equipment and processes, without stopping production between vehicles or without long delays to change tooling, and the ability to produce the same vehicle on different equipment and processes [22].

Flexible manufacturing has many advantages. First, it enables car manufacturers to cope with changes in demand and mitigate unexpected disruptions, as vehicles can be built in different assembly lines of the same manufacturing plant and, if feasible, transferred to another flexible plant in the organization's network. Then, although a high initial investment is required, in the long term, fixed costs are reduced and plants become more competitive [22].

6.1.3. Final resilient practices proposed

The final nine resilient practices proposed for the new Ecosilient Index are shown in Table 3.

As they are now nine instead of seven resilient practices, the original weights chosen in the article are no longer valid. The new weights of resilient practices should also be determined by Delphi method, since this method has proved to be beneficial for many similar indexes. However, unfortunately, the present thesis cannot cover this aspect.

Resilient Practices
Sourcing strategies to allow switching of suppliers
Flexible supply base / Flexible sourcing
Cooperation with upstream partners
Strategic stock
Lead time reduction
Flexible manufacturing
Creating total supply chain visibility
Flexible transportation
Coordination with downstream partners

Table 3: Resilient practices proposed

6.2. Proposal of additional green practices

6.2.1. Overview of the automotive sector with regard to greenness

With an annual worldwide production and sales of some 70 or 80 million vehicles, the automotive industry is the largest manufacturing sector in the world and, for a few years now, has had to confront many environmental pressures.

Obviously, the automotive industry cannot be reasonably blamed for all the current environmental issues, such as deforestation, desertification, habitat loss, species extinction and loss of species diversity, water shortages and resources depletion among others, but it is also true that the automotive industry has long been seen as an engine of economic growth and an indicator of prosperity for many countries. To that extent, the automotive sector has been the one that has contributed the more to the path of increased material consumption. The manufacture of cars demands vast quantities of materials, particularly virgin materials rather than recycled materials. The main materials used are steel, iron, aluminium and plastic [48].

Furthermore, the automotive sector and its products, in manufacture, use or disposal, are directly responsible for some of the burdens imposed by humanity. First, the construction of roads contributes to the fragmentation of ecosystems and, consequently, to the diminution of biodiversity. Second, the automotive industry is deeply implicated in carbon emissions, as road transport is currently the more polluting mode of transport.

Consequently, the automotive industry is currently facing an increasing trend of environmental concerns and innovations towards sustainability, but especially from the point of view of producing cleaner cars with lower emissions and fuel consumptions. As cars produce 85 per cent of life cycle carbon emissions during their use phase, 10 per cent in manufacturing and 5 per cent in disposal, automotive designers and engineers are working with suppliers to reduce the environmental impact of vehicles, developing innovations that can reduce carbon emissions and developing alternatives to hydrocarbon fuels [53].

On the other hand, the automotive sector is not only doing considerable efforts to reduce the environmental impact of its products, but also of its processes.

First of all, it should be noted that with to the introduction of lean production, mass production in the automotive sector became more efficient, as the main priority of lean manufacturing is removing waste in the broadest sense from any process. In other words, more can be done with less. Logically, this extends also to avoiding the wasteful use of resources, therefore to moving towards greater environmental efficiency also [52].

However, logically, more changes are needed in the automotive sector in order to achieve environmental sustainability. For this reason, nowadays, progresses have been made in terms of production, by reducing paint-shop emissions, implementing efficiency measures and reducing waste even further [52]. Moreover, many automotive companies have deployed environmental programs with their suppliers, in order to reduce the overall waste burden and the generation of pollution, implemented green practices related to internal environmental management, developed green supply chain management relationships with their customers, among others. Finally, reverse logistics also has an important role in decreasing the life-cycle environmental impact of cars [5].

In conclusion, although many progresses have been made in terms of sustainability in the automotive sector, more changes are still needed.

6.2.2. Additional green practices suggested

In addition to the practices proposed in the Ecosilient Index, after the review of the literature, the two following practices are suggested.

6.2.2.1. Green design of products

As a reaction against the waste of the current “throw-away” society, the interest in reverse logistics and remanufacturing from the advanced industrial economies is growing. Both initiatives imply social, business and environmental benefits and represent the first step in the creation of a circular value creation system, rather than the traditional and almost universal linear value chain. Moreover, in the automotive industry, the encouragement by the European Union of a recycling requirement in cars (to be 95 per cent able to be recycled by the year 2015) might stimulate car manufacturers to recover products after their use [48].

Due to the fact that the interest in relation to the management of products once they have been used is growing, the way in which companies approach the design of their products should change, as firms will need to design products that are easier to disassemble, to refurbish or to recycle after the initial use phase. This green design will benefit automotive companies both environmentally and financially, because generally “easier” also means “cheaper”. Furthermore, manufacturers should also improve the durability of their products in order to gain the maximum amount of revenue through the use of the minimum quantity of resources [48].

Within this context, approaches such as product modularity, which is the degree to which a product's components might be separated and recombined, and product upgradeability, which refers to the ease in which upgrades can be produced and applied to a product, may become increasingly important in the design process. Modular products are composed of detachable products that can be manufactured, assembled and serviced separately. This characteristic facilitates the reuse, recycle or remanufacturing of certain modules at the end of the lifecycle of a product. Moreover, an increase in modularity will decrease the time needed to disassemble the product and thus will reduce the cost of the remanufacturing processes. On the other hand, modules can also be regularly repaired, replaced or upgraded, which will enable to extend the life cycle of the product [48].

Obviously, it is particularly difficult to design with remanufacturing in mind a product that is very complex, as is the case of cars, which have several thousand parts, are made with many materials and need many different process steps to be produced. Moreover, the design team working on product design development needs information about the latest technology on materials and manufacturing. In other words, new product development needs cross functional cooperation in order to be successful [5]. However, the green design of products is a necessary step in order to achieve truly environmentally sustainable supply chains. Historically, the automotive sector has shown a modest extent of remanufacturing or renovation of components and sub-assemblies, and implementing green design could help to change this current dynamic [48].

6.2.2.2. Green procurement

As stated before, the automotive sector demands vast quantities of materials, particularly virgin materials rather than recycled materials. Consequently, insisting more on adopting green procurement could help to decrease the overall carbon footprint of the automotive supply chain and to reduce costs.

After studying the main characteristics of the automotive sector regarding procurement, some recommendations are proposed. First of all, car manufacturers should work on the minimization of the use and consumption of basic raw materials, energy and water, as more efforts can still be done nowadays [30].

Then, the recycling of material should be increased. For instance, in the case of aluminium, one of the main materials used in the car industry, the energy cost of creating the material is high compared with re-melting [48].

Moreover, special efforts should be made with regard to hazardous materials. The minimization or absence of toxic and hazardous substances in materials can help to comply with environmental regulations, decrease environmental impacts, reduce the costs of disposal of unrecyclable waste and avoid expensive local permit applications [30].

Finally, car makers should involve each trading partner and collaborate with them in order to find new products and solutions and increase the greenness of their procurement [30].

6.2.3. Final green practices proposed

The final nine green practices proposed for the improved Ecosilient Index are shown in Table 4. As in the case of resilient practices, the new weights of each green practice are not specified here and should also be determined by Delphi Method.

Green Practices
Green design of products
Green procurement
Environmental collaboration with suppliers
Environmental monitoring of suppliers

Green Practices
ISO 14001 Certification
To reduce energy consumption
To reuse/recycling materials and packaging
Environmental collaboration with the customer
Reverse logistics

Table 4: Green practices proposed

6.3. Relationships between paradigms

After analyzing all the resilient and green practices, it has been seen that one of the resilient practices, “strategic stock”, could negatively affect the green behaviour.

Strategic stocks allow supply chains to increase their resilience. As seen in previous chapters, having some inventories in strategic points can be very beneficial in case of an unexpected event interrupts the supply of parts and components. However, green paradigm prescribes the minimization of inventories, as they could generate material obsolescence. For that reason, the more redundant inventories there are in the supply chain, the less environmentally sustainable the supply chain will be [54].

So, for each company, the indicator Green Behaviour (B_G) should be calculated aggregating the Green Practices (P_G) according to their importance or weight, and subtracting a percentage of the implementation of the Resilient Practice “strategic stock”, as it affects negatively the green behaviour. This percentage should also be determined with Delphi method.

So, for each individual company j, the following formula is used to compute B_G:

$$(B_G)_j = \left(\sum_{i=1}^{9} w_{Gi} * (P_{Gi})_j\right) - \alpha_{ST} * (P_{RST})_j$$

Subject to:

$$\sum_{i=1}^{9} w_{Gi} = 1$$

$$(P_{RST})_j > 1$$

$$\alpha_{ST} > 0$$

Where:

- $(B_G)_j$ represents the green behaviour of the individual company j of the supply chain concerned.
- $(P_{Gi})_j$, with $i = 1, \dots, 9$, is the implementation level of practice i of green paradigm for the individual company j. After the improvement, a total of 9 practices are considered for each paradigm (see Tables 3 and 4). As stated before, the implementation level means the level of compliance of each practice in the company, and is assessed in a five point Likert scale from 1 to 5, where 1 is "practice not implemented" and 5 is "practice totally implemented".
- w_{Gi} , with $i = 1, \dots, 9$, represents the new weight of green practice i. This weight is common for all the companies that belong to the same supply chain.
- α_{ST} is a constant that represents the proportion in which having strategic stock could affect the green behaviour of the supply chain. This constant should be determined with Delphi method.
- $(P_{RST})_j$ is the implementation level of the resilient practice "strategic stock" for the individual company j. If $(P_{RST})_j = 1$, it means that the practice is not implemented at all, so there is not a strategic stock that could affect the green behaviour. For this reason, the restriction $(P_{RST})_j > 1$ has been added.

6.4. Modification in the Ecosilient Index construction

In this subparagraph, two different modifications regarding the calculation of the supply chain indicator are proposed, one for each paradigm: resilient and green.

First, due to the network structure of supply chains, when a disruption occurs in a particular company, it will be propagated and amplified, provoking severe negative consequences on the overall supply chain. As disruptions may occur everywhere throughout the supply chain, one weak point would be enough to jeopardize the performance of the overall supply chain

[2]. In other words, if one of the companies is almost not resilient and has a resilient behaviour close to 1, even if the rest of companies have a behaviour near to 5, the overall supply chain will have a specific point particularly vulnerable to disruptions. If that point suffers a crisis, as all companies are interconnected, it will affect the overall supply chain.

For this reason, the supply chain indicator according to the resilient paradigm could be calculated with the harmonic mean instead of the arithmetic one, as the harmonic mean tends to aggravate the impact of small outliers and mitigate the impact of large ones. In this case, this property is an advantage, as supply chains having companies with a particularly weak resilient behaviour will be more penalized. This will oblige supply chains to concentrate their efforts in improving vulnerable points with regard to resiliency.

So, the supply chain indicator according to the resilient paradigm, SCI_R, could be calculated applying the following formula:

$$SCI_R = \frac{n}{\sum_{i=1}^{n}\left(\frac{1}{(B_R)_j}\right)}$$

Where:

- n is the number of companies that belong to the studied supply chain
- $(B_R)_j$ represents the behaviour of the individual company j according to the resilient paradigm.

With regard to the green paradigm, the calculation of the supply chain indicator could be done with the geometric mean instead of the arithmetic mean. This is due to the fact that the geometric mean, compared to the arithmetic and to the harmonic one, is the most robust, which means that it is the least sensitive to outliers: the geometric mean is less sensitive than the arithmetic mean to high outliers and less sensitive than the harmonic mean to low outliers. In other words, the geometric mean is about equally sensitive to low outliers as to high outliers [55].

In contrast to resilient paradigm, it is not necessary to highlight low outliers in the case of the green paradigm. Although it is true that the greenness of the overall supply chain depends on the behaviour of all its companies, if one of them has a low degree of environmental sustainability, the consequences for the overall supply chain will not be as severe as in the case of resilience. However, the geometric mean has been preferred rather than the arithmetic one, in order to avoid possible distortions due to high values of green behaviour.

So, finally, the supply chain indicator according to the green paradigm, SCI_G, could be

calculated applying the following formula:

$$SCI_G = \sqrt[n]{\prod_{j=1}^{n} (B_G)_j}$$

Where:

- n is the number of companies that belong to the studied supply chain
- $(B_G)_j$ represents the behaviour of the individual company j according to the green paradigm.

6.5. Final Ecosilient Index proposed

In this chapter, the way to calculate the new Ecosilient Index, with all the improvements proposed, is detailed.

In the improved Ecosilient Index, there is now a total of 9 Resilient Practices (P_R) and 9 Green Practices (P_G), which are shown in Table 5.

Resilient Practices (P_R)	Green Practices (P_G)
Sourcing strategies to allow switching of suppliers	**Green design of products**
Flexible supply base / Flexible sourcing	**Green procurement**
Cooperation with upstream partners	**Environmental collaboration with suppliers**
Strategic stock	**Environmental monitoring of suppliers**
Lead time reduction	**ISO 14001 Certification**
Flexible manufacturing	**To reduce energy consumption**

Creating total supply chain visibility	**To reuse/recycling materials and packaging**
Flexible transportation	**Environmental collaboration with the customer**
Coordination with downstream partners	**Reverse logistics**

Table 5: Final Resilient Practices (P_R) and Final Green Practices (P_G)

For each company, the two indicators Resilient Behaviour (B_R) and Green Behaviour (B_G) can be calculated aggregating the correspondent individual sub-indicators, that is, Resilient Practices (P_R) and Green Practices (P_G), according to their new importance or weight, which will be determined with Delphi Method. However, when calculating the Green Behaviour (B_G), the negative influence of strategic stock for green behaviour will be now taken into account.

So, for each individual company j, the following formula is used to compute the indicator B_R:

$$(B_R)_j = \sum_{i=1}^{9} w_{xi} * (P_{Ri})_j$$

Subject to:

$$\sum_{i=1}^{9} w_{xi} = 1$$

Where:

- $(B_R)_j$ represents the resilient behaviour of the individual company j.
- $(P_{Ri})_j$, with $i = 1, \dots, 9$, is the implementation level of resilient practice i for the individual company j. A total of 9 practices are now considered (see Table 5).
- w_{Ri} , with $i = 1, \dots, 9$, represents the new weight of resilient practice i. This weight is common for all the companies that belong to the same supply chain.

And, for each individual company j, the following formula is used to compute the indicator B_G:

$$(B_G)_j = \left(\sum_{i=1}^{9} w_{Gi} * (P_{Gi})_j\right) - \alpha_{ST} * (P_{RST})_j$$

Subject to:

$$\sum_{i=1}^{9} w_{Gi} = 1$$

$$(P_{RST})_j > 1$$

$$\alpha_{ST} > 0$$

Where:

- $(B_G)_j$ represents the green behaviour of the individual company j.
- $(P_{Gi})_j$, with $i = 1, \dots, 9$, is the implementation level of practice i of green paradigm for the individual company j. After the improvement, a total of 9 practices are considered for each paradigm (see Table 5).
- w_{Gi} , with $i = 1, \dots, 9$, represents the new weight of green practice i. This weight is common for all the companies that belong to the same supply chain.
- α_{ST} is the constant that represents the proportion in which having strategic stock could affect the green behaviour of the supply chain.
- $(P_{RST})_j$ is the implementation level of the resilient practice "strategic stock" for the individual company j.

The Ecosilient Index for a particular individual company, $Ecosilient_j$, is calculated in the same way than before:

$$Ecosilient_j = w_R * (B_R)_j + w_G * (B_G)_j$$

Subject to:

$$w_R + w_G = 1$$

Where:

- $(B_R)_j$ represents the resilient behaviour of the individual company j and $(B_G)_j$ its green behaviour.

- w_R and w_G represent, respectively, the weight of resilient and green paradigms.

Then, the supply chain indicator according to the resilient paradigm, SCI_R, which represents the resilient behaviour of the overall supply chain, can be calculated applying the following formula:

$$SCI_R = \frac{n}{\sum_{i=1}^{n}\left(\frac{1}{(B_R)_j}\right)}$$

Where:

- n is the number of companies that belong to the studied supply chain
- $(B_R)_j$ represents the resilient behaviour of the individual company j.

On the other hand, the supply chain indicator according to the green paradigm, SCI_G, is calculated applying the following formula:

$$SCI_G = \sqrt[n]{\prod_{j=1}^{n}(B_G)_j}$$

Where:

- n is the number of companies that belong to the studied supply chain
- $(B_G)_j$ represents the behaviour of the individual company j according to the green paradigm.

Finally, the Ecosilient Index for a particular supply chain, $Ecosilient_{SC}$, is calculated aggregating both supply chain indicators with their corresponding weights:

$$Ecosilient_{SC} = w_R * SCI_R + w_G * SCI_G$$

Subject to:

$$w_R + w_G = 1$$

Where:

- SCI_R represents the resilient behaviour of the supply chain considered and SCI_G its

green behaviour.

- w_R and w_G represent, respectively, the weight of resilient and green paradigms.

The supply chain Ecosilient Index goes from 1 (no paradigm put into practice in the supply chain firms) to 5 (both paradigms are completely deployed in the supply chain firms).

Conclusions

In this thesis, after conducting a comprehensive review of the literature on resilient and green supply chains, a new and improved Ecosilient Index has been proposed.

First, after studying the current trends in the automotive sector regarding resilience and greenness, a total of four additional practices have been suggested. Then, the relationships between both paradigms, resilient and green, have been examined. Last, but not least, some modifications have been applied in the construction of the Ecosilient Index.

However, the improved Ecosilient Index is still at a theoretical level and has not been applied in real automotive supply chains. Therefore, it would be advisable to put into practice the two Ecosilient Indexes, the current and the new one, in order to compare them and validate the improvement suggestions proposed in the present thesis.

Glossary

CPFR (Collaborative Planning, Forecasting and Replenishment): The participants of the supply chain contribute to the elaboration of sales forecasts and replenishment plans in order to obtain a more precise visibility of the forecast demand and satisfy the future demand. It's a highly strategic management model.

ECR (Efficient Consumer Response): Strategy focused on improving the level of service offered to customers through a close cooperation of the enterprises with suppliers, distributors and retailers. Its main objectives are: to reduce the inventory levels, to decrease operating costs, to cut down supply cycles and enhance the customers' satisfaction. It's a highly developed model at operational level, with a high cost of implementation.

EDI (Exchange Data Interfaces): Transmission of data between distinct organizations by electronic means.

ERP (Enterprise Resource Planning): Business process management software that allows organizations to plan and manage all the issues related to production, distribution, shipments, inventory, accountability and human resources. Some examples of ERP systems are SAP, Oracle, and PeopleSoft, among others [9].

JIT (Just – In – Time): A procurement system in which materials, products, parts or sub-assemblies are delivered just when needed and in appropriate quantity. The objective of this system is having a minimum inventory level and, to achieve this goal, production and transportation times must be strictly controlled. In order to facilitate its implementation and to make the process simpler, suppliers must be located next to the clients. The JIT procurement is particularly suitable for bulky items, as they entail high transportation and storage costs. The main advantages of Just – In – Time philosophy are cutting manufacturing costs, improving companies' ability to respond to market shifts and simplifying quality control.

Six-Sigma Quality: Six-Sigma is a term coined to stress the continuous reduction in process variation to achieve near-flawless quality. When a Six Sigma rate of improvement has been achieved, defects are limited to 3.4 per million opportunities [9].

Toyota Production System: This technique was born in the factories of Toyota at the end of World War II. Its main purpose is to increase productivity and reduce costs, by eliminating all kind of unnecessary functions in the factories [51].

TQM (Total Quality Management): A management approach in which managers continually communicate with organizational stakeholders to emphasize the importance of continuous

quality improvement [9].

VMI (Vendor Managed Inventory): A procurement system in which the supplier locates his inventory in the client's warehouse, and both communicate continuously and in real time. In this system, the supplier knows at any time the stock levels, the demand, etc… and controls what he sends to the warehouse, in order to keep the stock levels between a minimum and a maximum previously agreed upon the client. To ensure that the supplier knows what to send and in which quantities, the client must do a long-term forecast. This system has many advantages: it reduces administrative procedures, as it is no longer necessary to issue purchase orders; the supplier can plan shipments better and optimize transport; it reduces inventory and it also enables to respond more quickly to demand changes. Finally, this type of procurement is particularly suitable for high-value products.

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