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Supply Chain Resilience Using the Mapping Approach

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1. Introduction

The supply chain environment is changing. Globalisation and changes demanded by stakeholders have influenced the attitudes of supply chain entities. These entities are becoming more professional, showing ever increasing levels of complexity, and adopting philosophies and management practices with the objective of increasing their levels of competitiveness.

Competitiveness is a critical factor in the success of a supply chain. Disturbances increase supply chain and may reduce it performance and competitiveness. It is therefore fundamental for a supply chain to be resilient to disturbances.

The chapter begins by defining and discussing the central concepts of resilience and disturbance, within the scope of supply chain management. Based on a mapping approach, a methodology is proposed for improving the supply chain's resilience to a disturbance proactively. After the selection of a supply chain disturbance, and the supply chain mapping, a mitigation strategy is chosen to make the supply chain resilient to this disturbance. A case study is presented to illustrate how the mapping approach support managers in the decision making process to make the supply chain resilient.

1.1 Background

In recent years, there has been an increase in the likelihood of the occurrence of disturbances. Natural catastrophes, such as what happened on the island of Madeira (Portugal) in February 2010, serious accidents resulting from technical faults, such as the oil spill that is taking place in the Gulf of Mexico, and economic crises, such as the one we are going through now with the international financial crisis caused by the failure of Lehman Brothers, are examples of events that cause disturbances that can have an adverse impact on supply chain management.

These disturbances can have characteristics that make them difficult to anticipate, and they can have severe negative consequences, not only in the supply chain entities where they directly occur, but also in the supply chains where the entities are integrated, since they generally lead to a cascade effect.

Disturbances may cause disruptions in flows of information, materials and/or finance in one or more supply chain entities. These disruptions may have a negative influence on a supply chain's normal operations, thus making it vulnerable and reducing its performance and competitiveness. Therefore, it is fundamental to make a supply chain resilient to disturbances.

The resilience of a supply chain entity is defined as the ability of that entity to be able to react to disturbances and return to its original state or a more desirable one (Christopher & Peck, 2004; Ponomarov & Holcomb, 2009). So, to make a supply chain resilient to disturbances, it is essential to understand the network that connects the supply chain entities. Therefore, it is essential to have an overall vision of the supply chain and of the principal characteristics regarding its entities and flows.

Supply chain mapping is a tool that allows for a macro-graphic representation of the supply chain (current state). When subjected to a disturbance, through this current state it is possible to build a potential future state. With the current state and the future state, we have the ability to identify if the supply chain is resilient to such disturbance. If the supply chain is not resilient to the disturbance, managers may take appropriate measures to respond to this disturbance, i.e., they may adopt mitigation policies, strategic or operational policies, to reduce the adverse effects of such disturbance and make the supply chain resilient.

The evaluation of the impact of the adoption of mitigation policies, in terms of supply chain performance and efficiency, will provide support to managers in decision making concerning the selection of the mitigation policy that needs to be adopted in order to increase the supply chain's resilience to a disturbance.

1.2 Objective

The main purpose of this study is twofold:

i.   To show that the mapping of the supply chain makes it possible to identify if the supply chain is resilient to a specific disturbance, and

ii. Support managers in making decisions concerning the adoption of mitigation policies, in the strategic as well as operational areas, in order to make the supply chain more resilient to certain disturbances.

To illustrate the way in which supply chain mapping can help managers to identify the most appropriate management strategy (mitigation policy) to make a supply chain resilient to a disturbance, a case study is presented based on a real supply chain in the automotive industry, considering a disturbance on the supply side. Consequently, we will discuss proactive and reactive mitigation policies that can be adopted by the supply chain to make it resilient to disturbances on the supply side. The case study represents a small part of the supply chain. In fact, in light of the objectives of this work and the complexity inherent in a real supply chain, it is sufficient to analyse only a small part of the supply chain.

2. Supply chain disturbances

The occurrence of disturbances that negatively affect a supply chain is an unavoidable fact, whereby all supply chains are inevitably at risk (Craighead et al., 2007). In this context, it is crucial for supply chain survival that managers identify, in a proactive manner, the disturbances that may potentially affect the supply chain and take measures, developing, for example, mitigation and/or contingency plans that help make the supply chain more resilient (i.e., less vulnerable).

Supply chain management in the face of disturbances is a subject that, in recent years, has motivated the interest of numerous researchers and practitioners. The works of Sheffi, Zsidisin and Svensson are examples of this.

In recent years there has been an increase in disturbances affecting the normal operation of the supply chain entities. According to Craighead et al. (2007), this is the greatest source of

pressure on supply chain entities intending to compete in the global market. They become vulnerable, which consequently reduces their performance and causes them grave financial difficulties. The supply chains thus lose their competitiveness. Competitiveness is a critical factor to the success of an organisation and/or a supply chain, so it is fundamental to make the supply chain able to be resilient to those disturbances.

A disturbance is a consequential situation that significantly threatens the normal course of operations of the affected supply chain entities (Zsidisin, 2000). Typically, this situation implies taking decisions/actions in order to minimize such effects.

The authors who have studied this subject do not reach consensus over the definition of disturbance, with it often being confused with the definition of disturbance source. In the context of this chapter, the term disturbance is defined as a foreseeable or unforeseeable event which affects the usual operation and stability of an organisation or a supply chain (Barroso et al., 2008). This is similar to Svensson's (2000), Hendricks' et al. (2008) and Kleindorfer & Saad's (2005) supply chain disturbance definition, an unplanned and unanticipated event that disrupts the normal flow of goods and materials in a supply chain.

For example, the supplier of automotive parts was severely affected by an earthquake that occurred on July 16, 2007 in Japan. As a consequence, one of its customers, a Japanese automotive manufacturer suffered a halt for several days (Pettit, 2008). An interruption in the operations of the supplier of automobile parts and of the automobile manufacturer is a disturbance example.

According to a study carried out by Autoeuropa, a Portuguese automotive assembler (Redmont, 2007, as cited in Azevedo et al., 2008), "some of the main disturbances identified by the principal partners in the supply chain are supplier delays (51%), others (25%), variations in production quantity (14%), quality problems (6%), problems in collection (3%) and damage in transport (1%)", Figure 1. Other disturbances frequently mentioned in the bibliography are:

i.   an unexpected increase in demand from a customer;
ii.   a general strike by drivers in a country;
iii. and infrastructure problems (roads, ports and communications). Regardless of the type of disturbance, the final result is always the same, unfulfilled orders.
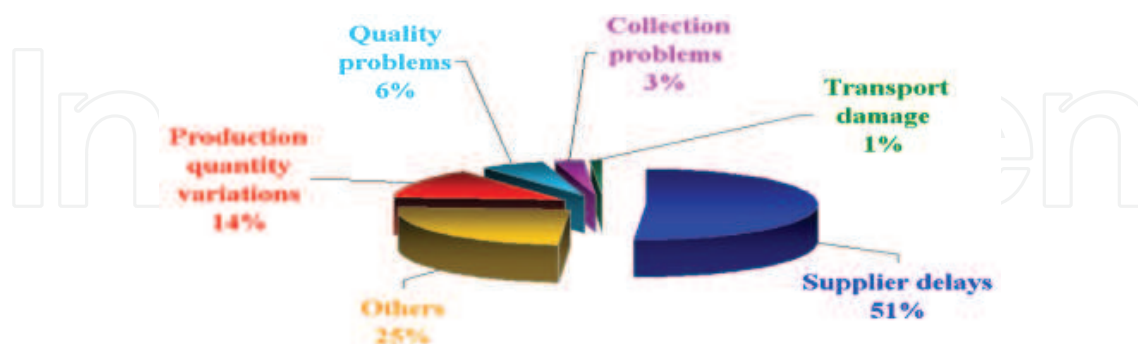

Fig. 1. Disturbances in an automotive SC entity in Portugal

The authors do not reach consensus over the term used to designate a disturbance. Some authors refer to disturbances as "disruptions" (Ponomarov & Holcomb, 2009; and Tuncel & Alpan, 2010), while others refer to it as "risk" (Chopra & Sodhi, 2004; and Goh et al., 2007), "uncertainty" (Mason-Jones & Towill, 1998) or even as "crisis" (Natarajarathinam et al., 2009). In this chapter, the term used is disturbance.

A disturbance may be characterized based on some criteria, particularly, i) it may be critical for a SC, ii) it may occur during a short or long period of time, iii) it may have a local or a global impact, and iv) it may be foreseen a greater or lesser time in advance of its occurrence (Barroso et al., 2008).

A disturbance may occur: i) within an organisation (for example, a machine breakdown or a strike), ii) outside an organisation but internal to the supply chain (for example, a supply delay or distorted information throughout the supply chain), or iii) external to the supply chain (for example, an earthquake or a flu epidemic).

The occurrence of a disturbance may have severe negative effects only on the supply chain entity it directly impacts, or may also affect, in whole or in part, the supply chain of which the entity forms a part. In fact, the negative effects of the disturbances frequently cascade through the supply chain, due to dependencies (time, functional and relational) between supply chain entities (Svensson, 2004). This behaviour affects the capacity of the entities that constitute the supply chain to fulfil commitments made, reducing their service level.

The effect of a disturbance on a supply chain may involve different degrees of severity. Severity is defined as the number of entities in a supply chain whose outbound and inbound flow is affected by an unplanned event (Craighead et al., 2007). The degree of severity of a certain disturbance depends on factors specific to the structure of the supply chain (density, complexity, and node criticality), and supply chain mitigation capabilities (recovery and warning).

In the light of a disturbance with negative effects for a supply chain, the level of competitiveness of the supply chain previously reached (before the disturbance occurrence) is compromised. The ideal solution is for managers of the supply chain entity or the supply chain to formulate proactive recovery plans to minimize the negative effects of the disturbances that may affect the supply chain. But, in the absence of this, at least a reactive recovery plan should be in place. Although this is not the ideal solution, it is better than having no recovery plan.

The performance of a supply chain that is not resilient to a disturbance shows a typical profile that was defined by Asbjørnslett & Rausand (1999), Figure 2. In general, the performance of a supply chain entity or a supply chain when subject to a disturbance drops sharply, taking some time to recover until it reaches the same performance level as before the disturbance occurred (line A). In the event of a disturbance mitigation policy being adopted, the drop in performance is not so sharp, the period of time that the supply chain takes to recover its performance being shorter and the final performance level (before maintaining stability) can be the same as before the disturbance occurred (line B) or even greater (line C).
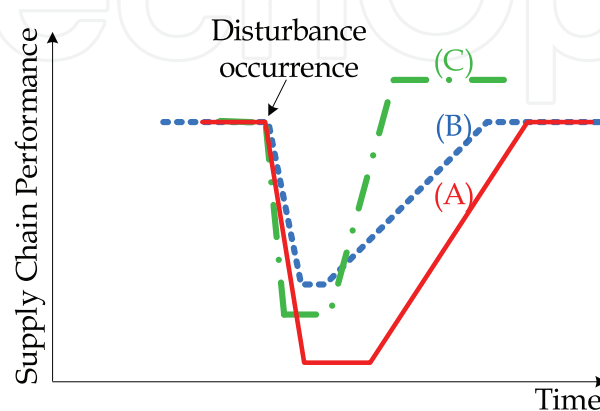

Fig. 2. Performance profile of a supply chain

So, it is crucial that managers identify the likelihood that disturbances will occur and then take the appropriate measures to respond to each disturbance. The adoption of measures suitable for the management of supply chain disturbances will give the supply chain the ability to quickly return to its original state, or even a better state (Peck, 2005; Ji & Zhu, 2008; and Carvalho & Cruz Machado, 2007), and thereby demonstrate resilience. The measures to be taken to limit the negative effects of a disturbance can be of 3 types: i) to reduce the likelihood that such a disturbance will occur, ii) to reduce the negative effect of the disturbance, or iii) both.

3. Supply chain resilience

Supply chain resilience is a relatively new area of management research. Although in the available literature it is possible to find some definitions of resilience in different contexts, in the supply chain context some researchers, namely Peck (2005) and Mitroff & Alpasan (2003), define supply chain resilience by associating it with the ability to recover from or adjust easily to adversity or change, i.e., supply chain disruptions caused by disturbances. Fiksel (2006) proposes an identical definition, but considers that a resilient system will have the ability not only to "survive and adapt in face of turbulent change", but also "grow".

The traditional tool to manage uncertainty is risk management. According to Pettit (2008), the "traditional risk assessment approach cannot deal with unforeseeable events", the concept of supply chain resilience filling this gap.

Using multidisciplinary perspectives, Ponomarov & Holcomb (2009) propose the following definition of supply chain resilience: "The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function." This definition considers several key elements when a supply chain disruption occurs, namely, response and recovery to the same or a better state, and retention (or maintenance of) the same control over structure and function.

The concept of supply chain resilience is, in this chapter, defined as the supply chain's ability to react to the negative effects caused by disturbances that occur at a given moment in order to maintain the supply chain's objectives.

A resilient supply chain entity or supply chain recovers better from hardships (Mitroff & Alpasan, 2003). However, resilience is more than simply the ability to recover. It also implies a certain level of flexibility and the ability to adapt to environmental influences. Therefore, resilience is one of the prerequisites for sustainable economic development (Hamel & Valikangas, 2003). It may also be viewed as a source of competitive advantage. Resilience is the key to developing a strategic plan that is sustainable and capable of producing results that are better than those of less resilient competitors (Stoltz, 2004).

3.1 Mitigation policies

One way for a supply chain to become resilient is through the implementation of adequate mitigation policies.

The awareness and need for supply chain disturbance management has grown rapidly this century, driven by regulatory compliance requirements and stakeholders' demands. Also, there is a greater understanding of the real costs of supply chain disturbances. Consequently, supply chain disturbance management has become one of the major concerns of many

organisations and supply chain managers who direct their efforts to improving the resilience of their supply chain entities or supply chains. Accordingly, adequate management policies must be defined in order to a supply chain entity or supply chain become resilient, meaning an entity or supply chain with the abilityand the means to reduce negative disturbance effects.

When main disturbances occur, many supply chains tend to break down. In this case recovery takes a long time. Certain policies will enable a supply chain to effectively manage the inherent fluctuations regardless of the occurrence of major disturbances. These policies will allow a supply chain to become more resilient in the face of major disturbances (Tang, 2006).

The mitigation policies can be defined according to the moment at which actions are taken to mitigate the disturbance effects, Figure 3. Tomlin (2006) describes two general approaches for dealing with disturbances: mitigation and contingency policies. Both are defined prior disturbance occurring, however, mitigation policies are employed prior to disturbances, whereas contingency policies are generally post-disturbance techniques. In the case of mitigation policies, the supply chain entity takes some action in advance of a disturbance (and so incurs the cost of the action regardless of whether a disturbance occurs). With contingency policies, the supply chain entity takes action only in the event of a disturbance occurring. So, mitigation policies are essentially more proactive in nature, while contingency policies are more reactive (Craighead et al., 2007).
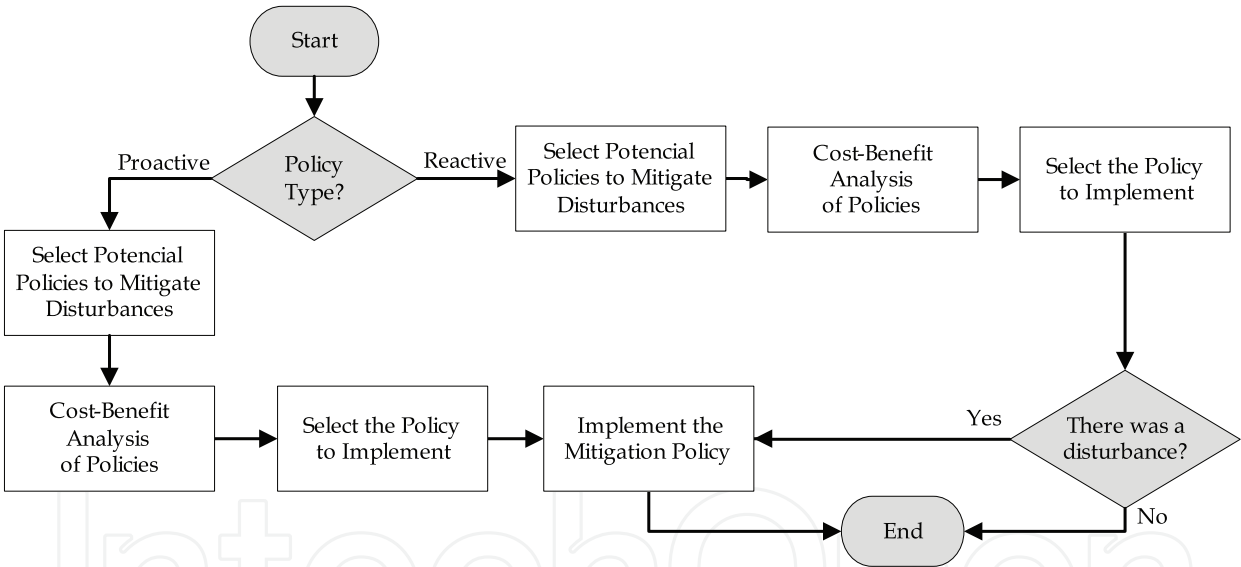

Fig. 3. Framework to mitigation policies implementation

A proactive policy emphasizes preventive plans for what can be done to avoid specific disturbances or prevent their occurrence as far as possible. For those unavoidable disturbances, the emphasis is to mitigate their negative consequences and transform them into business opportunities and/or increased value for the customer.

A reactive policy to disturbances emphasizes supply chain readiness. The focus is on how to increase the supply chain's capacity to respond to the disturbance faced individually and collectively.

The selection of which policy to adopt generally depends on the negative potential consequences to the supply chain of the disturbance or the likelihood of the disturbance occurring. Many policies for the management of disturbances are in conflict with the supply chain's traditional goals and processes, and vice-versa. Consider, for example, the trade-off

between efficiency and redundant inventory: building redundant inventory in the supply chain will function as a buffer to maintain continuous operations. However, it will also drive up costs and lead to lower efficiency.

A review of available literature provides a huge number of policies used to mitigate the negative effects of supply chain disturbances. Since the disturbances most cited by managers in the automotive industry (section 2) are from the supply side, in this chapter only disturbances with this characteristic will be analysed.

Consider the disturbance source "supplier failure". Failures with inbound materials and services can arise from a supplier failure. An example of the ramifications of supply failure would be the shutdown of production lines due to a lack of incoming materials from a supplier, which can then result in the loss of business and customer goodwill. Some authors propose different policies to mitigate supplier failures (Table 1).

Mitigation policy	References
Safety stock	Baker (2007); Zsidisin et al. (2000)
Multi-sourcing	Baker (2007); Zsidisin et al. (2000); Svensson (2003)
Collaboration with supplier	Zsidisin et al. (2000); Christopher & Peck (2004)
Coordinate relationships in the supply chain	Giunipero & Eltantawy (2004)
Increase information sharing	Giunipero & Eltantawy (2004); Li et al. (2006)
Supplier selection process	Levary (2007)
Well stocked pipeline	Zsidisin et al. (2000)
Supply chain reengineering	Christopher & Peck (2004)
Create a supply chain disruptions management culture	Christopher & Peck (2004)

Table 1. Supply side mitigation policies

The use of inventory redundancy in situations of supply uncertainty is, in most cases, recognized as a possible mitigation policy. For example, Chopra & Sodhi (2004) cite "increase inventory" as a mitigation policy, whilst Stoltz (2004) states that "the strategic disposition of additional capacity and/or inventory at potential 'pinch points' can be extremely beneficial in the creation of resilience within the supply chain".

The creation of redundancies or flexibilities is one of the main policies for resilience design: the redundancy capacity may or may not be used; it is this additional capacity that would be used to replace the capacity loss caused by a disturbance. Flexibility, on the other hand, entails restructuring previously existing capacity.

The sourcing policy should be employed considering the fact that there is an overall association between the sourcing and the occurrence of disturbances in firms' inbound and outbound logistical flows. However, due the interdependencies among groups of suppliers, the buying organisation that wants to adopt multiple sourcing policies for disturbance mitigation should create a portfolio of suppliers that do not maintain relationships with one another.

The supplier selection process, the use of collaboration with the various entities involved working together, the increase of information sharing, and the use of safety stock to buffer against variations in supply are also policies to which reference is frequently made.

Typically, supplier selection is based on the acquisition price. However, for the organisation to be resilient, the supplier selection criteria should also be extended to other issues such as quality and organisational parameters/capabilities.

Intense collaboration among the various supply chain entities is crucial in order to attain a resilient supply chain in the turbulent business environment in which they currently operate. It may also facilitate upgrading suppliers' performance and allow them to become more capable. However, such a policy is difficult to implement. Only a small number of collaboration initiatives will be successful, and collaboration appears more and more difficult to achieve.

Increasing information sharing among supply chain entities will improve supply chain resilience, since the negative impact of lack of visibility in the supply chain is reduced.

Some authors also refer other policies, such as building a level of trust among trading partners, coordinating relationships with supply chain entities, passing the responsibility for the consequences of disturbances on to suppliers, having a well-stocked supply pipeline, performing supply chain re-engineering, and creating both an agile supply chain and a culture of disruption management.

4. Supply chain mapping

4.1 Traditional value stream mapping

Value Stream Mapping, referred to at Toyota as material and information flow mapping (Rother & Shook, 1999), is based on the fundamental principle of Lean Manufacturing, and has been used in several organisations as a powerful tool to identify and reduce waste, and to help to design production systems incorporating the lean concept. It is a relatively simple tool and has been widely applied to processes in need of performance improvement (Jones & Womack, 2002).

This tool illustrates material and information flows across the entity by focusing on production activities, working backwards from the entity's shipping dock to the entity's receipt of materials. Through value stream mapping a common set of tools, metrics and language is produced, facilitating systems analysis and decision making. The process of developing the value stream map makes understanding the product, material and information flows, value stream metrics and the interaction of processes possible. It is a big picture view of the system and aims to improve the whole value stream and not just to optimize parts of the value.

So, value stream mapping can be used as a road map that reveals the obstacles to continuous flow and the opportunities for reducing waste through the use of other lean techniques. As it explains how lean techniques can reduce waste in the value stream, it is known primarily as a communication tool. However, it is also used as a strategic planning tool, and a change management tool.

Many authors have studied the implementation of Value Stream Mapping effectively, namely, Ohno (1988), Womack et al. (1990), Womack & Jones (1998), and Rother & Shook (1999).

4.2 Extended value stream mapping

Over time, the most simple supply chain will begin to change. New entities and/or flows, such as suppliers, end-users, and parts or materials, can be added or excluded as changes that are not part of original planning. For that reason, a supply chain map of the current state is an indispensable managerial document, as it helps visualize the network that

connects the business to its suppliers and to its downstream customers, and allows the identification of problematic areas and support process decisions. It can be seen as the starting point to improving supply chain management, increasing both efficiency and cost-saving efforts, allowing the identification of places where likely cost savings can be made due, namely, to excess or scarce inventories, inefficient processes, unnecessary actions, expedited shipments, lost visibility, and correct them.

Extended value stream mapping is a tool that takes material and information flows and effectively illustrates them across the supply chain. As an extension of the mapping process, supply chain mapping allows a clear view and understanding of the supply chain entities' actual capabilities as well as the whole chain dynamics. In general, supply chain mapping efforts focused on the flow of a specific product or product family (Lambert, 2008) and covers two echelons of the supply chain.

Gardner & Cooper (2003) define a supply chain map as a visual representation of the linkages and entities of a supply chain, and all of the process and decision points that occur throughout a supply chain, both upstream and downstream. According to Craighead et al. (2007) the mapping process should illustrate the different entities that are connected by the material flow, the relationships between entities, and the direction of the material flow (unidirectional or bidirectional). In line with Schroeder (2000), in supply chain mapping all processes may be included and the mapping focuses on how material, information and money flow in the upstream and downstream directions, and also within supply chain organisations.

Discussion on supply chain mapping cases is found in both the work of academics and practitioners (Hines & Rich, 1997; Naim et al., 2002; Childerhouse & Towill, 2003).

4.3 Supply chain map

In supply chains with multi-country operations, the manager may not have a clear view of the exact flow of material, information, and money. Developing a supply chain map which clearly shows suppliers, their contributions, the various flow types, and the way the business is organized, can lead to supply chain decision making more effective. Given the complexity of supply chains, supply chain mapping may exclude non-critical entities to keep the map simpler. Although a map of the supply chain is a simplified representation of the system, with respect to both entity relationships and types and direction flows, the essence of the environment in which the supply chain operates is captured.

A supply chain map should be easy to build and use, sufficiently comprehensive but not excessively detailed, intuitive in its use of visuals, and effective in building alternatives. Thus, a map would have standardized icons to allow easy identification of supply chain entities and also understanding of the flows between each entity (Farris II, 2010). It is important to note the role of the size, shape and colour of the assorted icons as a means of visual communication. Gardner & Cooper (2003) present a set of conventions, albeit incomplete, derived from the lean manufacturing model (Rother & Shook, 1999).

The choice of what to represent from what viewpoint can have a profound effect on supply chain strategy. The processes of both developing and disseminating the map should lead to a common understanding of the supply chain that would include what was deemed important to managing or monitoring the chain, as well as what the supply chain structure is or will be.

A supply chain map can either form an integral part of the planning process or a tool for implementing the supply chain strategy. Thus, according to Gardner & Cooper (2003), it may alert to possible constraints and offers a basis for: i) enhancing the strategic planning process, ii) easing the distribution of key information, iii) facilitating supply chain redesign

or modification, iv) clarifying channel dynamics, v) providing a common perspective, vi) enhancing communications, vii) enabling monitoring of supply chain strategy, and viii) providing a basis for supply chain analysis. So, a supply chain map provides a supply chain interrelationships framework, but does not provide the detail that allows to manage it.

Despite the fact that the mapping process can be used and found in many scientific areas, the map's appearance may vary significantly.

According to Gardner & Cooper (2003) three main distinctions are made between supply chain mapping and process mapping: i) orientation, ii) level of detail represented in the map, and iii) purpose for creating the map, Table 2.

	Supply chain mapping	Process mapping
Orientation	• Focuses on how material, information, and money flow: i) in both the upstream and downstream directions, and ii) through an organisation.	• Can be defined as the focus of the mapping procedure. • Generally directs its attention to a single operation or system within an organisation.
Detail	• Emphasizes high-level measures such as volume, cost, or lead time.	• Tends to break down a process into activities and steps.
Purpose	• Is strategic. • Is used i) to help create a supply chain that conforms to a strategy, or ii) as a check to make sure the current chain is set up properly to fulfil that strategy.	• Is typically tactical. • The origin of that map comes from the recognition of a problem area and an attempt to improve operating efficiency. The goal is to make changes to the current operations of the organisation.

Table 2. Supply chain and process mapping

4.4 Type of maps

Supply chain maps can be built from a descriptive or prescriptive perspective (Gardner & Cooper, 2003). However, the purpose of the mapping is to gain an intimate understanding of the supply chain. There are different techniques and tools used to develop maps, and there are different types of map.

When someone refers to the expressions "supply chain" and "mapping", remembers the Supply Chain Operations Reference model. The Supply Chain Council (2006) has developed the Supply Chain Operations Reference model for representing a supply chain configuration by capturing the state of five core processes of its constituent entities: i) plan, ii) source, iii) make, iv) deliver, and v) return. Thus, it provides a unique framework that links business processes, metrics, best practices and technological features into a unified structure to support communication among supply chain entities, and also to improve the effectiveness of supply chain management and related supply chain improvement activities. This model allows the buy-make-deliver operations of a supply chain entity to be improved, and extends it beyond a single entity's boundaries.

The maps can depict organisations, flows, facilities, and/or processes (Gardner & Cooper, 2003), and results from the collection of different kinds of data. Therefore, Fine (1998) suggests three different types of map depending on the type of information they represent:

i.   Organisations (e.g., focal organisation),
ii.   Technologies (e.g., engine valve), and
iii. Capabilities (e.g., Just In Time delivery and supply chain management).
Supply chain maps may or may not depict geographical relationships. When supply chain maps are drawn on geographic maps, they allow spatial visualization. While cartographers might insist that a true map has spatial relationships depicted, for a supply chain map this information may be present or absent (Juga, 1995).

5. Research methodology

The purpose of a supply chain is to bring to its customers the product and services they need where and when necessary. All business processes within the supply chain must focus directly or indirectly on this goal. As competitiveness is a critical factor in the success of a supply chain, it is vital for a supply chain to be resilient to disturbances. Supply chain resilience to a disturbance can be achieved by redesigning the supply chain, which, in turn, can be done using the mapping approach as it allows both the supply chain to be understood and problematic areas identified. Therefore, in the context of this study, after identifying a potential disturbance that cause changes in the normal operation of the supply chain (reducing its competitiveness), it is necessary to redesign the supply chain (through the adoption of proactive and/or reactive policies), to mitigate adverse impacts and speed recovery.

Different policies may entail different implementation costs and different effectiveness to mitigate the adverse impact of a disturbance on the supply chain. Therefore, the selection of the mitigation policy to be implemented must take into consideration a cost-benefit analysis in relation to all the policies likely to being adopted.

To determine a future state of supply chain management and the progression from 'what is the current state?' to 'what should the redesigned supply chain be?', a methodology comprising six phases is proposed, Figure 4. Phases 4, 5 and 6 of the methodology are performed only if the supply chain is not resilient to the disturbance selected in phase 2.

Phase 1 - Mapping the current supply chain

To obtain a transparent overview of the related organisations and processes, the supply chain should be described and visualized. Thus, the first phase of the methodology is to provide a map of the supply chain under analysis. The mapping of the supply chain should be developed in pictorial form using diagrams. The most important information for each supply chain entity must be captured, such as products and materials sourced or bought, costs and prices, quantities, replenishment lead time and whether or not it is a sole or single source or a key customer, respectively. Sources of information used should be provided by each supply chain entity.

The supply chain map allows to identify i) the main supply chain constraints, ii) the relative importance of each supply chain entity, and iii) their main characteristics. Additionally, it should allow to identify iv) the supply chain dynamics, and v) their complexity (the complexity depends on both the entities that comprise it and the flow of materials that circulates between them). Thus, a supply chain map allows to illustrate the core processes that must be considered when trying to improve the resilience of a supply chain to a disturbance. Six major dimensions for supply chain maps can be considered: i) supply chain entities; ii) relational links between supply chain entities; iii) material flows; iv) information flows; v) management policies; and vi) lead times.
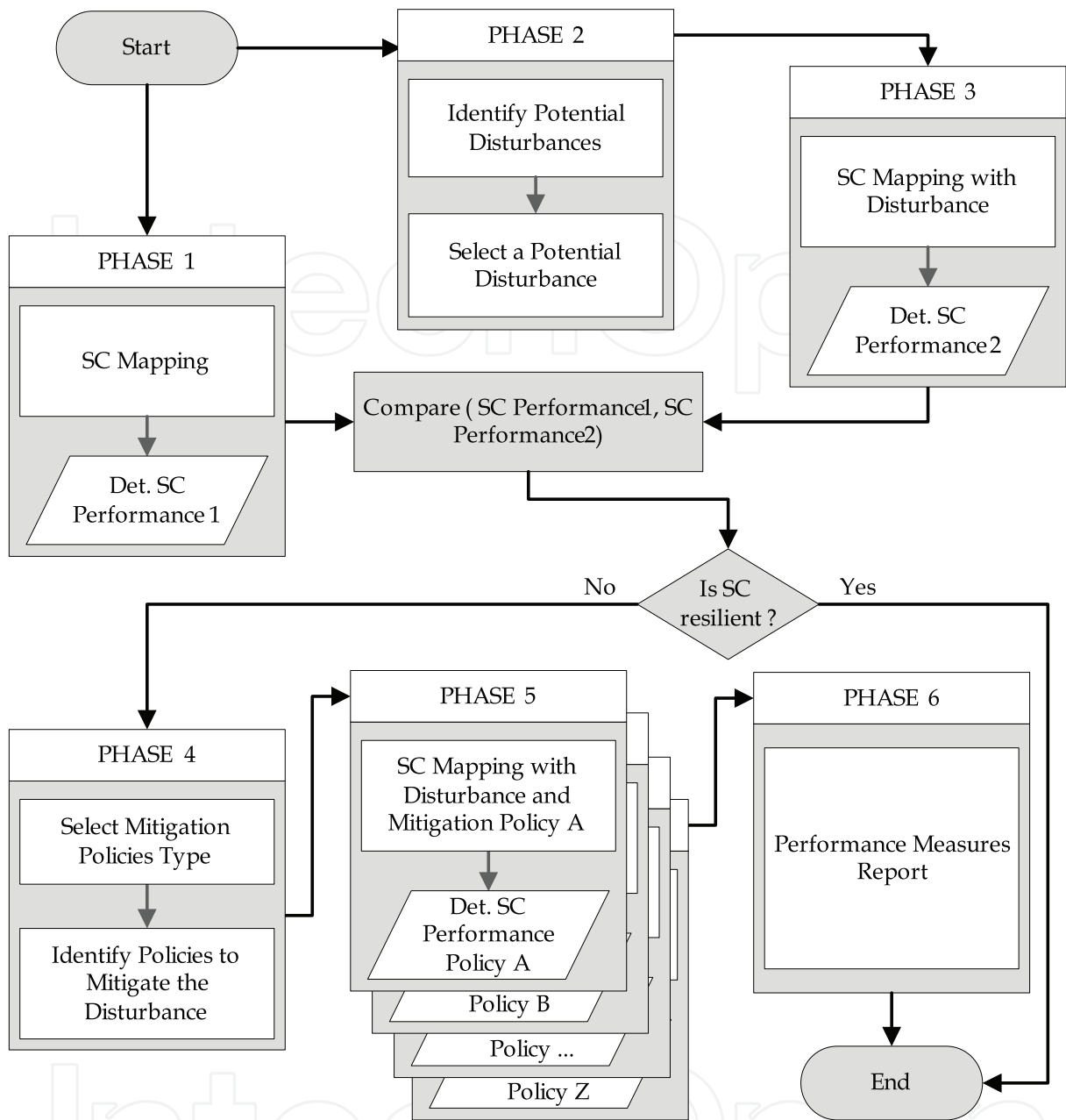
Fig. 4. Research methodology proposed

Phase 2 – Identifying a potential disturbance in the supply chain

The second phase is to identify potential disturbances in the supply chain that make it vulnerable. These vulnerabilities are related to specific events that have the potential to cause a break in the supply chain. Their disturbance source could lie within the supply chain, such as a strike, or externally, such as a severe weather event. Whatever the source, the adverse impact of disturbances on supply chain performance may be different. Thus, associated with a supply chain disturbance, there is a risk that depends on the likelihood of it occurring and the negative impact that it may have on supply chain performance. Accordingly, this phase is mainly focused on the selection of the disturbances that may occur in the supply chain in the near future, and that have higher probability of occurring and/or high negative impact on the supply chain.

Phase 3 - Mapping the supply chain considering the impact of the potential disturbance identified in phase 2

The third phase builds upon work conducted in the previous two phases of the methodology. A map of possible future state of the supply chain under analysis is formulated from the mapping of the current state of the supply chain (performed in phase 1) and the selected disturbance (from phase 2). At phase 3, it is possible to visualise the negative effects of the disturbance on supply chain performance and verify if the supply chain is resilient to the disturbance. If the supply chain is not resilient to the chosen disturbance, it is necessary to proceed to phase 4 to choose actions that may allow to move towards supply chain resilience.

Phase 4 - Identifying a set of reactive or proactive policies, to mitigate the supply chain management problems caused by the chosen disturbance

The fourth phase of the methodology allows, as a first step, to decide what type of mitigation policies to adopt, and as a subsequent step, to choose some policies to be implemented to make the supply chain resilient to the selected disturbance (phase 2).

Phase 5 - For each mitigation policy chosen, mapping the supply chain considering the negative impact of the potential disturbance identified in phase 2 on the supply chain

In the fifth phase, some supply chain mapping scenarios (of potentials future states) are built. These scenarios result from the adoption/implementation of mitigation policies chosen in the previous phase (phase 4). This allows to investigate if each scenario makes the supply chain resilient to the selected disturbance.

Phase 6 - Performance measurement report for all supply chain mapping scenarios

Finally, in the sixth phase of the methodology, a report outlining performance measures determined for each scenario is presented. This report allows a comparative analysis of the various scenarios. At this phase, each scenario is characterized by some performance measures aimed at the end customer, including the service level and lead time. Supply chain cost, which includes the costs associated with the adoption/implementation of mitigation policy, is also considered, where appropriate, as is the production cost in the supply chain entities and the transportation costs between supply chain entities that contribute to satisfying the end customer.

The methodology proposed supports decision making within supply chain management. It allows the manager to act in a proactive manner, trying different scenarios (implementing mitigation policies) to make the supply chain resilient to disturbances.

6. Case study

To illustrate the way in which supply chain mapping allows to improving proactively the supply chain's resilience to the negative effects of disturbances at the supply side, a case study was developed based on a real supply chain in the automotive industry. AutoEuropa (an automotive assembler) and some of its Portuguese suppliers make up the supply chain, and were involved in a research project named "Supply Chain Management: Design for Resilient Systems", which is being developed in Portugal.

To support proactive decision making in the selection of the mitigation policy to be implemented, the methodology proposed in section 5 was applied to the case study.

6.1 Description

The case study represents a small part of a supply chain in the automotive industry. In fact, in the light of the objectives of this chapter and the complexity inherent in the actual supply chain, the analysis of only a small part of the supply chain is enough.

The supply chain is defined by five entities: the customer, the assembler, and three parts suppliers (1st Tier A, 1st Tier B, and 1st Tier C), Figure 5.

The supply chain is responsible for the production and distribution of product X, which consists of three parts (A, B and C), in accordance with the materials tree, Figure 6.
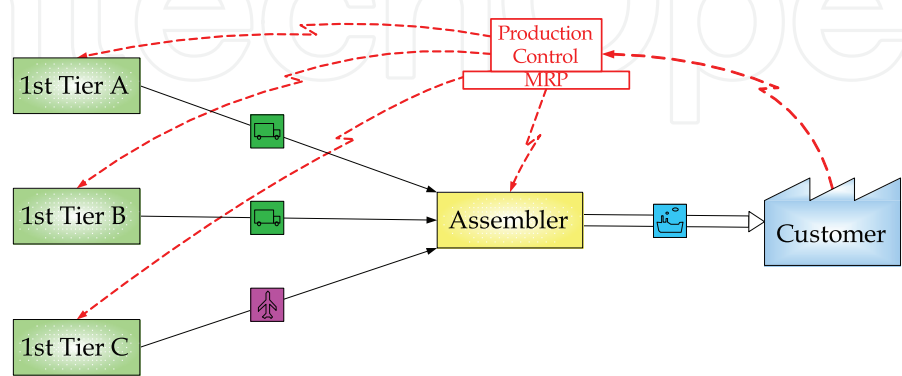

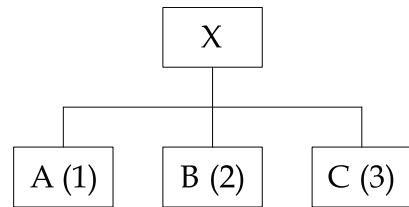Fig. 5. Case study supply chain

Fig. 6. Product X materials tree

In light of the location of the suppliers' and assembler's facilities, and the pre-established supply conditions between the supply chain entities, road and air transport are used to transfer the parts from the suppliers to the assembler. The transport of product X from the assembler to the customer is undertaken by sea. All transports have a cost which depends on a fixed cost, and a variable cost. In turn, the variable cost depends on the quantity of product transported, the unit cost of the transport, and the transport time.

On a daily basis, the customer places orders of 100 units of product X to the assembler. Customer demand is pulled through the supply chain. From the application of Material Requirements Planning (MRP), the requirements for parts are generated and immediately transmitted to their suppliers. Each part of product X is supplied by a single supplier.

The assembler, along with its suppliers, works according to the Just In Time philosophy and no middle inventories are held.

For simplification proposes, the capacity of the assembler and all the suppliers is considered unlimited, and it is assumed that the customer will wait for the order to be delivered even when a stockout exists.

The assembler produces daily the quantity of the product necessary to satisfy the order place by the customer. The quantity to be produced is determined considering that the proportion of parts produced correctly is 98%. The period of time from the moment the assembler receives an order to the moment it is shipped, the lead time, is 1 day. The cost to the assembler of

producing 1 unit of product X is 5 UM. The inventory cost tax is 20% per unit per year. If a stockout occurs, there will be a backorder cost of 1,52 UM per unit per day.

The 1st Tier A produces part A daily. The quantity produced depending on the order placed daily by the assembler, and the proportion of parts produced correctly (95%). Regarding part A, the number of parts per product unit X is 1. The production lead time is 1 day. The production of 1 unit of part A represents for 1st Tier A a cost of 1 UM. In the event of a stockout, there will be a backorder cost of 0,30 UM per unit per day.

All entities in the supply chain work 22 days a month and do not interrupt their work for holidays.

The characteristics of the assembler and the three suppliers are shown in Table 3.

Entity	N_Part (Units)	Yield (%)	Lead Time (Day)	Production Cost (UM/Unit)	Backorder Cost (UM/Unit.Day)
Assembler	1	98	1	5	1,52
1st Tier A	1	95	1	1	0,30
1st Tier B	2	100	1	1	0,30
1st Tier C	3	99	1	2	0,61

Table 3. Supply chain entity characteristics

The transport time from the assembler to the customer is 2 days. The number of shipments per day is unitary. The fixed cost of transport is 50 UM per shipment and the variable cost is estimated from the quantity of product X transported, the unit cost of 0,01 UM, and the transport time.

The 1st Tier A order is transported to the assembler by road. The lead time is 1 hour (0,125 days). The frequency of the order transport is twice daily. The other item flow characteristics between all entities are shown in Table 4.

Flow from ... to ...	Transport mode	Lead Time (Days)	Cost t (UM)	Fix Cost (UM)	Frequency (per Day)
Assembler $\rightarrow$ Customer	Sea	2,0	0,01	50	1
1st Tier A $\rightarrow$ Assembler	Road	0,125	0,02	100	2
1st Tier B $\rightarrow$ Assembler	Road	0,125	0,01	80	1
1st Tier C $\rightarrow$ Assembler	Air	0,5	0,10	200	1

Table 4. Flow characteristics between entities

6.2 Performance measures

In order to make the supply chain resilient proactively, it is necessary, in a first step, make a diagnosis regarding the performance of current state. Then, using the same performance measures, it is necessary to assess potential future states, those resulting from the disturbance occurrence and/or those resulting from the implementation of mitigation policies.

So, to compare the current state and the potential future states (considering a disturbance) performances, two performance measures were defined, supply chain cost (SC Cost) and supply chain lead time (SC Lead Time).

For an order h, the supply chain cost includes all relevant costs, namely, the ones associated with production and holding inventory (Prod_Holding Cost), stockout (Backorder Cost), and transportation of the product (Transportation Cost).

$$SC\,Cost_h = \mathrm{Pr}od\_Holding\,Cost_h + Backorder\,Cost_h + Transportation\,Cost_h \tag{1}$$

For an order h of product X, the production and holding inventory cost at the supply chain is defined as follows:

$$\mathrm{Pr}od\_Holding\,Cost_h = \sum_{i=1}^{I}\left[\begin{array}{l}(\mathrm{Pr}od\,Quant_{hi} \times Cost_{hi}) + \\ + (Inventory_{hi} \times Inventory\,Cost_{hi} \times Lead\,Time_{hi})\end{array}\right] \tag{2}$$

where,

   I is the number of supply chain entities;

   ProdQuant$_{hi}$ is the number of units produced of order h, at entity i;

   Cost$_{hi}$ is the unit cost of production of order h, at entity i;

   Inventory$_{hi}$ is the average inventory level, at entity i;

   InventoryCost$_{hi}$ is the cost of holding inventory for one unit of the product h over a unit time period, at entity i;

   LeadTime$_{hi}$ is the period of time required to produce the order h, at entity i.

In the event of a stockout affecting an item, it is assumed that the customer awaits restocking. The backorder cost depends on the cost of shortage of one unit, the number of units that are stockout per unit of time, and the time necessary to satisfy the customer's order. Thus, for an order h, the backorder cost is defined as follows:

$$Backorder\,Cost_h = \sum_{i=1}^{I}\left[B\_order\,Cost_{hi} \times \sum_{z=1}^{Time} Quant_{hiz}\right] \tag{3}$$

where,

   Time is the period of time between the moment that the order h should have been delivered and the moment at which it is delivered to entity i;

   Quant$_{hiz}$ is the quantity of an item of h stockout per unit of time z, at entity i;

   B_order Cost$_{hi}$ is the shortage cost of an unit of h by unit of time, at entity i.

The products flow between entities of the different echelons. So, there are product transportation costs. The transportation cost has two components, the fixed cost and the variable cost. The fixed cost is incurred whenever a shipment is dispatched, regardless of the quantity transported. The variable cost is a function of the transported quantity, the transportation time, the transportation frequency, and the unit transportation cost per unit time.

As there is no product flow between all entities in the supply chain, a dummy variable must be employed with a value of 1 if there is a flow of products between two entities and a value of 0 if there is no flow. So, the transportation cost of an order h is defined as follows:

$$
\begin{aligned}
Transportation\,Cost_h &= \sum_{i=1}^{I-1}\sum_{k=1}^{I}\left(Flow_{hik} \times FixCost_{hik} \times Freq_{hik}\right) + \\
&\quad + \sum_{i=1}^{I-1}\sum_{k=1}^{I}\left(Flow_{hik} \times Cost\,t_{hik} \times TranspQuant_{hik} \times LeadTime\_t_{hik} \times Freq_{hik}\right)
\end{aligned}
\tag{4}
$$

where,

$Flow_{hik}$ is a dummy with a value of 1 if there is a flow of h from entity i to entity k, or 0 otherwise;

$Fix\ Cost_{hik}$ is the fixed cost associated with transport of order h from entity i to entity k;

$Cost\_t_{hik}$ is the unit cost associated with transport of order h from entity i to entity k;

$TranspQuant_{hik}$ is the number of units transported from entity i to entity k;

$LeadTime\_t_{hik}$ is the period of time from the moment at which the order h is shipped by entity i and the moment at which entity k receives the order;

$Freq_{hik}$ is the number of shipments of order h per unit time from entity i to entity k.

The lead time associated with the customer's order depends on the lead time associated with all the activities that are necessary along the supply chain to fulfil the order, both value added and not added. In order to simplify calculation of the supply chain lead time, it is assumed that products only flow between consecutive echelons of the supply chain. So, for a customer order h, the supply chain lead time is defined as follows:

$$SC\ Lead\ Time_h = \sum_{e=1}^{E-1} \left[\underset{\forall i \in e; k \in e+1}{Max} \left(Lead\ Time_{hi} + LeadTime\_t_{hik} \right) \right] \qquad (5)$$

where,

E is the number of echelons in the supply chain.

6.3 Following the methodology

The application of the methodology proposed results in the construction of scenarios. The base case scenario (1) corresponds to the current state of the supply chain. After identifying a potential disturbance, scenario (2) was defined, in order to identify the performance behaviour of the supply chain when subjected to the disturbance. If supply chain is not resilient to the disturbance, scenarios (3) to (6) are constructed from scenarios (1) and (2) with the implementation of policies to mitigate the negative effects of the disturbance. The performance of a supply chain when subject to a disturbance drops, taking some time to recover. The supply chain disturbance is verified at 1st Tier B, from day 3 to day 6. Then, for each scenario, the performance indicators SC Cost and SC Lead Time were determined, for a period of 10 days, to involve the entire recovery period.

To represent the supply chain from a macro perspective, the Value Stream Mapping (VSM) method was used with the eVSM(TM) software, version 5.21. The experiments were performed with a connection to Microsoft Excel. Input data were collected from Excel and output data were stored in the same worksheet.

The eVSM(TM) software was designed to complement lean implementation methodologies and focus on process analysis rather than supply chain entities. Because this software is used to gather a macro view of a supply chain, it is necessary to establish analogies between processes and supply chain entities. Therefore, each supply chain entity can be moulded as a process with specific characteristics. By replicating the entities models and linking the material and information flows, a supply chain representation can be obtained.

6.3.1 Phase 1 - mapping the current supply chain

The supply chain mapping, base case scenario (1) was carried out in accordance with the characteristics of the entities involved, the material and information flows and the modes of transport used, shown in section 6.1.

The management of a supply chain entity involves costs. For example, associated with fulfilling an order of product X, the assembler may have production, holding and/or backorder costs.

The average cost of production of 102 units of product X, with a unit production cost of 5 UM, is 510,00 UM. During the day, the average stock of product X is 51 units. The unit cost of production is 5 UM, and the annual rate of cost of ownership is 20% per unit. Thus, ownership of a product for 1 day, at the assembler's facilities, costs 18,94 UM. So, the average production and holding inventory cost (i.e., considering all supply chain entities) is 528,94 UM, for an order of 100 units of product X.

In this phase, which corresponds to the base case scenario, no stockout is considered to exist. The frequency of the deliveries to the customer is 1 order per day, and the dummy variable associated with the transport between the two entities is 1.

The transportation cost of an order between the assembler and the customer, defined by the fixed cost and the variable cost, is 52,00 UM. The average transportation cost of a customer order of 100 units of product X through the supply chain (i.e., considering the flows between all supply chain entities) is 547,81 UM.

A graphical view of the supply chain was obtained, Figure 7. In the bottom right-hand corner it can be seen that the period of time between the moment at which the customer places an order and the moment at which the customer receives it is 4,17 days, and that the average cost of managing 1 order along the supply chain is 2041 UM.

For the period analysed (10 days), the SC Cost is 20405,22 UM (Table 5).

Entity	Prod_Holding Cost (UM)	Transportation Cost (UM)	SC Cost (UM)
Assembler	5289,39	520,00	5809,39
1st Tier A	1108,64	2002,55	3111,19
1st Tier B	2117,27	802,55	2919,82
1st Tier C	6411,82	2153,00	8564,82
Supply chain	14927,12	5478,10	20405,22

Table 5. Scenario (1) costs for the analysed period of 10 days

6.3.2 Phase 2 - identifying a potential disturbance in the supply chain

In this phase it is necessary to define the disturbance whose effects are intended to be analysed. Taking into consideration that "supply delay" is the main disturbance that affects the supply chain under study (as mentioned in Section 2), this disturbance was chose. It was considered that a failure in the 1st tier B, supplier of part B, on the third day of the period of analysis (10 days), generates an increase in the production lead time from 1 to 4 days.

6.3.3 Phase 3 - mapping the supply chain considering the disturbance impact

To analyse supply chain performance when a disturbance occurs, scenario (2) was built. Under this scenario, in addition to production, holding inventory, and transportation costs, the supply chain cost also takes backorder cost into consideration.

For the assembler, the average backorder cost is 151,52 UM per day, given that the shortage cost of 1 unit per day of product X is 1,52 UM and that, as a consequence of a delay of 4 days in the delivery of part B, during this period of time there is a stockout of 100 units of product X.
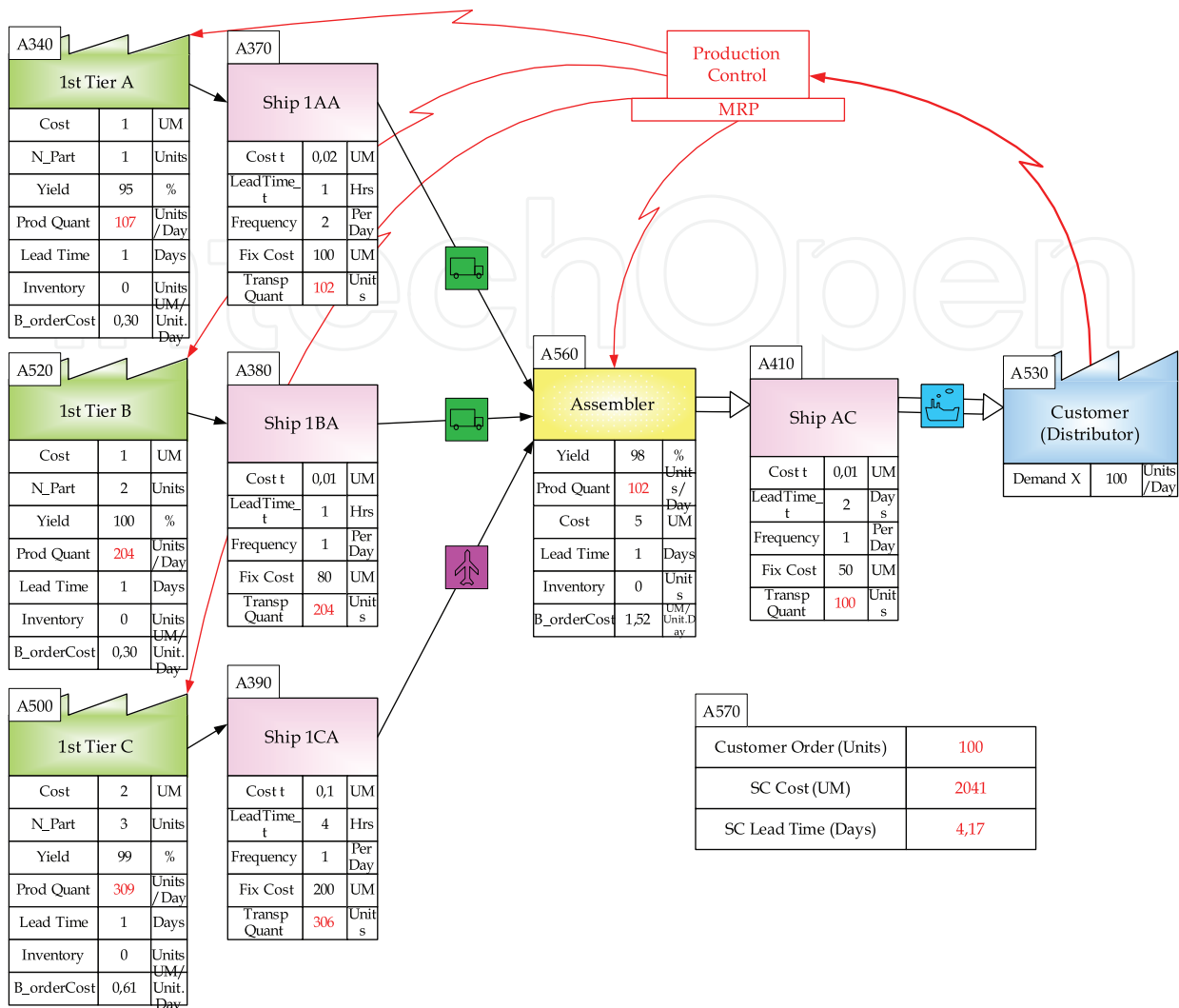
Fig. 7. Scenario (1) for an customer order of 100 units of product X

Under scenario (2), as a consequence of the disturbance at 1st Tier B, the maximum SC Lead Time increases by 93% in relation to scenario (1) (from 4,17 to 8,04 days). For the analysed period of 10 days, the SC Cost increases by 7,9% in relation to scenario (1) (from 20405 to 22019 UM), Table 6.

Entity	Prod_Holding Cost (UM)	Transportation Cost (UM)	Backorder Cost (UM)	SC Cost (UM)
Assembler	5289,39	320,00	1515,15	7124,55
1st Tier A	1108,64	2002,55	-	3111,19
1st Tier B	2117,27	482,55	618,18	3218,00
1st Tier C	6411,82	2153,00	-	8564,82
Supply chain	14927,12	4958,10	2133,33	22018,55

Table 6. Scenario (2) costs for the analysed period of 10 days

6.3.4 Phase 4 - identifying policies to mitigate the disturbance

Through the analysis of scenario (2), it is possible to notice that:

i.   The assembler has no alternative suppliers for part B. An identical situation is found for all the other parts.

ii. Like the assembler, the 1st Tier B has no buffer stock. There is no inventory of raw materials, work in progress, and final products.

It is therefore possible to say that the occurrence of a disturbance in 1st Tier B prevents the supply of part B to its direct customer, the assembler. It may also be noted that, due to this fact, the assembler cannot supply its customer. In other words, given the characteristics of the supply chain, a disturbance in one entity of the supply chain causes a cascading effect on all the entities that depend, directly or indirectly, on that part.

In order to analyse the resilience of the supply chain when mitigation policies are applied to the disturbances, in phase 4 of the methodology, two proactive policies are chosen: (P1) holding of a buffer stock and (P2) having two suppliers for part B.

6.3.5 Phase 5 - supply chain mapping considering the mitigation policies

In phase 5, scenarios (3) and (4) were constructed from scenario (1), and scenarios (5) and (6) from scenario (2). Mitigation policy (P1) was applied to scenarios (3) and (5), i.e., it was considered that 1st Tier B holds a buffer stock of the quantity necessary to satisfy two days of assembler demand. Under scenarios (4) and (6) mitigation policy (P2) was applied. Part B orders are subdivided equally by two suppliers. Each supplier has unlimited capacity, so, if necessary, each supplier can provide the total demand for part B.

6.3.6 Phase 6 - performance measurement report for all scenarios

A summary of the performance measurements results for the six scenarios built are presented in Table 7.

Scenario	Characterisation		Performance Measures (10 days)	
	Disturbance	Mitigation Policy	SC Cost (UM)	Max (SC Lead Time) (Days)
1	-	-	20405	4,17
2	✓	-	22019	8,04
3	-	P1	20714	4,17
4	-	P2	21311	4,17
5	✓	P1	20933	6,04
6	✓	P2	20991	4,17

Table 7. Scenarios results

6.4 Results analysis

The performance measures analysis obtained from each scenario, Table 7, allows the decision maker to assess the behaviour of the supply chain in different situations and decide which policy to adopt to mitigate (or not) the negative effects of the disturbance.

As revealed by the case study results, if a "supply delay" occurs at a 1st Tier supplier, delaying the items availability (scenario (2)), the maximum SC Lead Time would increase by 93% (from 4,17 to 8,04 days) compared to base case scenario, scenario (1), if no mitigation policy has been implemented.

If a mitigation policy using multiple suppliers (policy P2) is implemented, scenario (6), the maximum SC Lead Time can be reduced from 8,04 to 4,17 days (the same as scenario (1)),

and SC Cost will decrease by about 4,7% (from 22019 to 20991 UM). However, the policy P2 implementation will represent in the SC Cost an increase of 2,87%, if no disturbance occur (scenario (4)). It is also possible to verify that, relatively to policy P2, the policy P1 implementation represents a lower SC Cost (20933 *versus* 20991 UM), and a lower reduction in the maximum SC Lead Time (6,04 *versus* 4,17 days), relatively to scenario (2).

7. Conclusion

Nowadays, supply chains are rooted within a turbulent environment, being subject to numerous events that cause disturbances in their management. Supply chain disturbances are increasing in number and frequency, affecting the normal operation of supply chains and, consequently, their ability to meet commitments.

Regardless of the disturbance that affects the supply chain, the final effect observed in the supply chain is unfulfilled customer orders. Therefore, supply chains must be resilient to disturbances and must react effectively to their negative effects. Otherwise they can loose competitively.

Supply chain resilience to a disturbance can be achieved by redesigning the supply chain to mitigate adverse impacts and speed recovery. To determine a future state of supply chain management and the progression from 'what is the current state?' to 'what should the redesigned supply chain be?', a methodology is proposed. The methodology, comprising six phases, supports managers in making decisions, in a proactive manner, trying different scenarios from the implementation of mitigation policies, to make the supply chain resilient to a selected disturbance. The methodology is based on the mapping approach.

A case study is developed based on a real supply chain in the automotive industry. The methodology proposed is applied to the case study. Supply chain mapping is carried out based on the characteristics of the entities involved, on the material and information flows and on the modes of transport used. For each entity, some relevant management characteristics are identified. Also, the flow of materials between entities is characterised by some attributes. To represent the supply chain from a macro perspective, the Value Stream Mapping (VSM) method is used with the eVSM(TM) software, version 5.21. The experiments are performed with a connection to Microsoft Excel.

Through the application of the proposed methodology to the case study it is possible to verify that supply chain mapping allows to have a clear view and understanding of the supply chain entities' actual capabilities. It is also possible to verify that the supply chain is not resilient to the "supply delay" disturbance due to its management characteristics, namely, absence of inventories and adoption of a single supplier policy. The built of different scenarios allow yet to analyse the supply chain behaviour considering two proactive mitigation policies.

8. Acknowledgment

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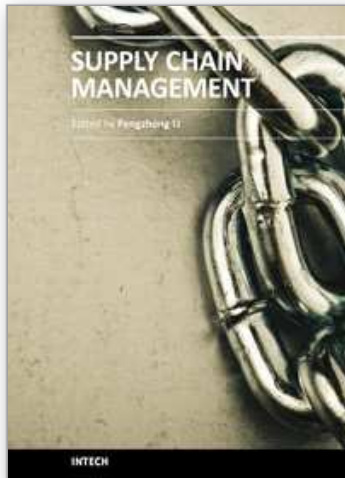
Supply Chain Management

Edited by Dr. pengzhong Li

The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.

How to reference

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