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Robust supply chain risk management.

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Robust Supply Chain Risk Management

INTRODUCTION

Supply chain risk management is an increasingly important activity due to the process of globalization and outsourcing which carriers an additional requirement of coordination among the supply chain participants. In these complex supply chains the performance of its participants is affected by the actions of other members of the supply chain, by regulators, and by technological change, for example (Oliveira, 2012).

Nonetheless, Chopra and Sodhi (2004) have reported that most companies develop plans to protect against high-probability risks in their supply chains but ignore high-impact low-likelihood risks, whose likelihood and impact is difficult to estimate. For this reason, it is crucial to use techniques to estimate and consider uncertain disruption parameters. Robust optimization (Kouvelis, Kurawarwala, & Gutierrez, 1992; Mulvey,Vanderbei, & Zenios, 1995; Tang, 2006 b; Sheffi & Rice, 2005; Hahn & Kuhn, 2012; Gulpinar & Oliveira, 2012) aims to find solutions that are feasible under all the possible values assumed by the parameters. The policy computed using robust optimization is optimized to take into account these uncertainties.

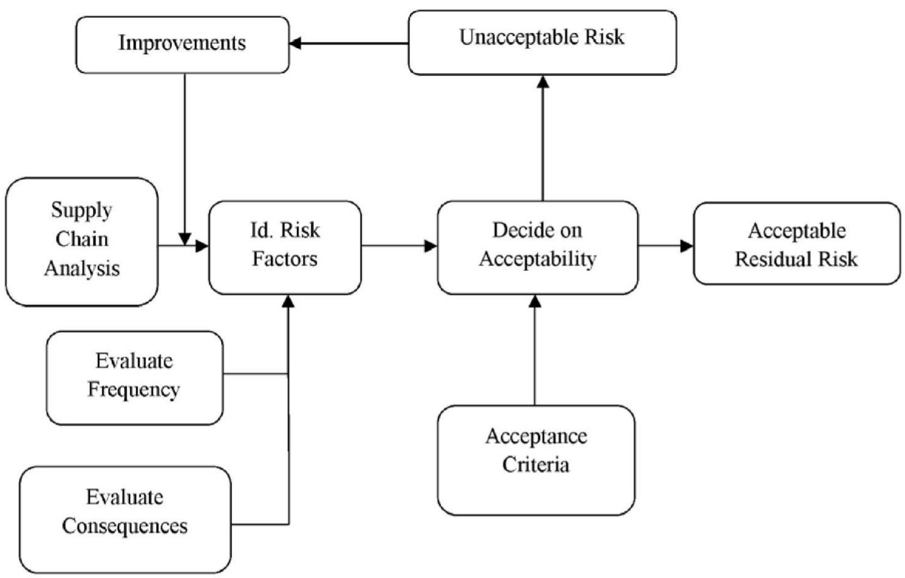
In this chapter we revise the literature on supply chain risk management, including risk assessment, risk perception and risk management policies, and we survey the robust optimization methods proposed in the literature to address these issues.

SUPPLY CHAIN DISRUPTION RISKS

In this section we revise the concept of supply chain risk management (SCRM) and the different approaches for classification of risks in supply chains. Tang (2006 a) has defined SCRM as the coordination between the supply chain members in order to guarantee profitability and continuity.

There are different supply chain risk classifications. For example, Chopra and Sodhi (2004) have categorized supply chain risks into disruptions, delays, systems, forecast intellectual property, procurement, receivables, inventory, and capacity. In their definition, disruption risks include natural disasters, labour disputes, supplier bankruptcy, war and terrorism, and dependency on a single source of supply. Tang (2006 a) has categorized supply chains risks in two types: operational and disruption risks. Operational risks are related to the existing problems such as uncertain demand, uncertain supply, and uncertain cost. On the other hand, disruption risks concern the major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, and economic crises such as currency devaluation or strikes. In addition, he mentions that the business impact associated with disruption risks is much larger than the operational risks.

Furthermore, as shown in Figure 1, typically, the risk assessment and management process follows several steps. First the risk analyst needs to assess the frequency and consequences of the risk factors; then he needs to decide on the risks that are not acceptable and take the required measures to improve them. Finally, there is always a residual level of risk that the manager accepts to



live with as it may be more expensive to tackle than its perceived consequences.

One important area of risk analysis, due to the complexity of the risk assessment exercise, is catastrophic risk. Kunreuther and Useem (2009) have argued that, regardless of the risk assessment methodology, there are always four basic elements for assessing the catastrophic risks (as represented in Figure 2): a) hazard, e.g., hurricanes, terrorism or pandemics; b) the inventory of properties, humans, and the physical assets which are exposed to risk; c) the vulnerability of the structures or people at risk; and d) the human and property loss after measuring of vulnerability. It is beneficial to separate the losses into direct and indirect losses while dealing with catastrophes in this model. Direct losses contain fatalities, financial losses, and the cost to repair a construction, or re-establish a service. Indirect losses have longer impacts in the future like slower growth, lost income, and company bankruptcies. In the next section we review several methods used for supply chain disruption risk management, as this is a very important catastrophic risk at which supply chains are possibly exposed, emphasising robustness methods, and providing a framework for disruption risk analysis in supply chains.

ROBUST SUPPLY CHAIN DISRUPTION RISK MANAGEMENT

In this review we focus on supply chain disruptions, as these are at the top of the management concerns (see Figure 3), and are fundamentally different from the risks arising from machine failures or demand uncertainty, as they completely stop the production flow and typically persist for longer (Kleindorfer & Saad, 2005); for these reasons, the impact of supply chain disruptions can be catastrophic, although their likelihood is very low. As can be seen in Figure 3, which we adapted from Makowski, Papier, and Walter(2012), supply chain

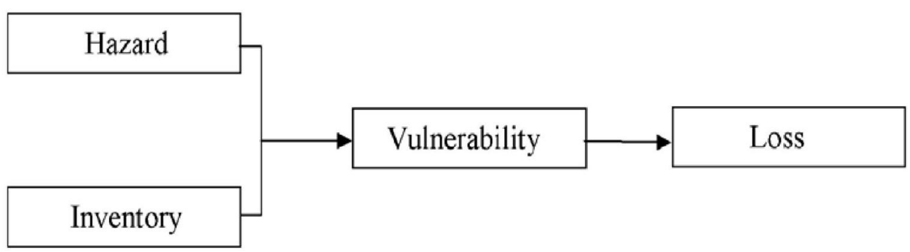
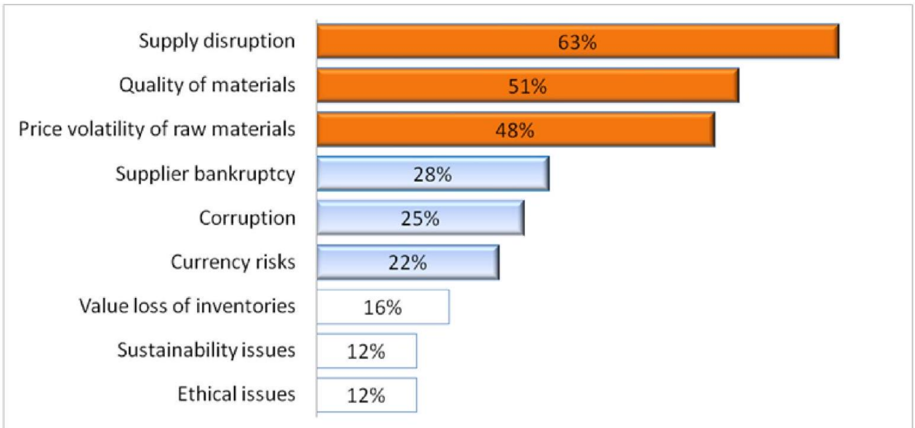


Figure 3. Ranking of supply chain risks, adapted from Makowski et al. (2012)



disruption is the most important risk considered by management, followed by the quality of the materials and price volatility.

Next we focus on the methodologies used for disruption risk assessment in supply chains, discuss issues with risk perception, and describe how robust optimization is used for managing these risks. Finally, at the end of this section, we provide an illustrative example.

Disruption Risk Assessment

In the context of supply chains, Knemeyer, Zinn and Eroglu (2009) have argued that a significant gap still exists for estimating the probability of specific events in a pre-determined location and that, for this reason, simulation is a natural tool for evaluating the impact of catastrophes in supply chains. For example, Deleris and Erhun (2005) have proposed scenario analysis and Monte-Carlo simulation to analyze risk in a multi-product, multi-echelon supply chain which includes catastrophes caused by employee strikes, the shortage of components, severe political instability in the various regions, and disruptions caused by hurricanes.

In addition, using system dynamics simulation, Wilson (2007) has analyzed the impact of a transportation disruption on a five-echelon supply chain when it occurs between two echelons, to assess the impact of these disruptions on stock out levels, inventory fluctuations, and the behaviour of goods in transit. Wilson simulates both a traditional supply chain and a vendor-managed inventory system in which demand information is shared upstream, showing that disruptions have the biggest effect when they happen close to the middle echelons of the supply chain, and that information sharing reduce some of the impacts of disruptions.

Most papers on supply chain disruption assume that the firm has complete information about the disruption risk. However, very often it is not easy to estimate disruption risk accurately due to the rare occurrence of catastrophic events and because suppliers are often reluctant to share disruption information with their clients. Two solutions to deal with this problem have been suggested in the literature. The first is to improve forecasting; the second is to design an incentive mechanism that leads suppliers to disclose information about disruptions. Tomlin (2009) has adopted the first solution, using a Bayesian model to update the firm's forecast of the reliability of its supplier and obtaining the optimal policy when forecast is involved with sourcing and inventory decisions. Yang, Aydin, Babich and Beil (2009) have used the second solution: they used a single-period, single supplier, single manufacturer model in which the supplier is subject to a random production disruption (the probability of which is the supplier's private information). The manufacturer offers the supplier a set of contracts, including transfer payment, order quantity, and the penalty cost, and the supplier selects a contract which maximizes its profit. Yang et al. (2009) have demonstrated that the manufacturer can encourage the supplier to reveal its correct reliability level.

It seems, from our literature review, that most models implicitly assume that the disruption probability is known. However, as in reality this is not the case, it is crucial to consider the robustness of the planning decisions as the disruption probability and impact are uncertain. Next, we consider the role of risk perception of catastrophic risks and its effect on the output of risk assessment process.

Perception of Disruption Risks

Whereas risk assessment focuses on objective losses such as financial costs, risk perception is concerned with the psychological and emotional factors associated with risk. Research has demonstrated that the perception of risk has an enormous impact on behaviour, regardless of the objective conditions (Kunreuther & Useem, 2009). It has been shown that people view hazards with which they have little personal knowledge and experience as highly risky (Slovic, 2000). For example, in the case of unfamiliar technologies with catastrophic potential, such as nuclear power, the general public tends to overestimate risk.

Researchers have also found that people tend to evaluate catastrophes by considering one end of the probability spectrum or the other. That is, for some people such events will certainly happen, for others they will certainly not happen and few are in the middle (for very low probability events people move toward the "will not happen" end of the distribution, e.g., Kunreuther & Useem, 2009). For example, some people may perceive the likelihood of a disaster causing damage to their property as being very low that they cannot justify themselves to buy an insurance against natural disasters and investing in loss-protection measures. If a disaster happens, people then tend to overinvest in preventing a recurrence. Protective measures are consequently adopted when it is too late (Kunreuther, 2002).

In order to consider the perception of supply chain disruption risk Ellis, Henry and Shockley (2010) have explored the relationship between the impact, the likelihood and the overall supply disruption risk, attempting to identify product and market factors that affect the buyer's perceptions of the probability and impact of supply disruptions. They have shown that both the probability and impact of supply disruption influence the buyers' whole perceptions of supply disruption risk. On the other hand, the study by March and Shapira (1987) on banking executives shows that buyers and purchasing managers tend to pay more attention to probability when forming their perceptions of overall supply disruption risk.

In summary, people's risk perceptions are affected by judgmental biases when facing catastrophic risks in any context (Kahneman, Slovic, & Tversky, 1982). For instance, after terrorist attacks in September 11, many of people living in the USA rejected to fly because they believed that the likelihood of a terrorist attack was considered high, even though the actual probability was very low due to high security policies conducted after 9/11 (Kunreuther & Useem, 2009). Next, we look at studies that have incorporated risk assessment and disruption risk perception in risk management strategies.

Disruption Risk Management Strategies

Risk perceptions are very important when setting up risk-management systems. For example, in developing effective risk management strategies for mitigating losses from natural and unnatural disasters leaders of public agencies and private and non-profit organizations use risk-assessment studies considering the factors that influence risk perception and choice (Grossi, Kunreuther, & Patel, 2005).

In a separate study, Kleindorfer and Saad (2005) have proposed a framework for disruption risk management, based on Shavell (1984), which includes both risk assessment and risk mitigation activities. In this framework a firm seeks a trade-off between risk mitigation investments and the expected costs of disruptions, weighed by the disruption probability. The optimal level of risk mitigation investment minimizes the total cost. Cohen and Kunreuther (2007) present the major elements of a conceptual framework for risk analysis of catastrophic events in supply chains according to the work of Kleindorfer and Saad (2005). The framework unites risk assessments and risk perception in order to obtain risk management strategies followed by an evaluation of the proposed strategies (Figure 4).

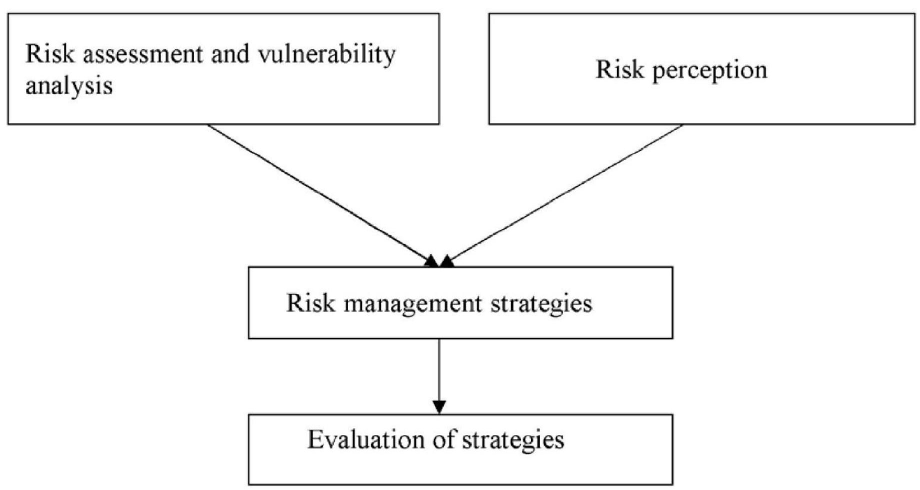
Knemeyer etal.(2009), based on the framework proposed by Cohen and Kunreuther (2007) for risk analysis, suggest that one of the main stages in risk management is the recognition of supply chain threats. The four crucial stages are: recognition of the main supply chain threats, estimation of probabilities and losses, consideration of alternative countermeasures, and finally selection of the countermeasures.

Based on our review it seems that the lack of quantitative research in supply chain risk management. Next, we introduce robust optimization and then we discuss how it be utilized for risk assessment of disruption risks while taking into account the perception of these kind of risks in the decision making process.

Robust Optimization Methods for Disruption Risk Management

Robust optimization is an approach to compute the optimal policy which needs to be feasible under all possible scenarios, and taking into account the decision maker's risk-averse preferences (Hahn & Kuhn, 2011). Mulvey et al. (1995) mention that approaches to robust optimization differentiate between two contradictory criteria of robustness: first, solutions are considered to be robust if they are almost feasible for each scenario; second, there are solutions that are robust if they are close to optimal for each scenario. Another approach to robustoptimization is worst-case scenario (Kouvelis et al., 1992; Gulpinar & Oliveira, 2012): this approach does not consider scenario probabilities and does not use the scenario-specific control variables in the optimization model.

In the context of supply chain risk management, robust optimization has been used for quantifying operational risks. Hahn and Kuhn (2012) combined a value-based performance metric and risk management which creates an important tool



for increasing the shareholder value in supply chains facing operational risks. They used robust optimization methods are used to deal with operational risks in physical and financial supply chain management because of the uncertainty of future events.

Tang (2006 b) mentions that in the absence of the precise measures of the likelihood and the potential loss of a disruption, companies are more enthusiastic to conduct certain robust strategies for mitigating disruptions risks. In addition, these strategies have two important characteristics: first, these strategies allow supply chain to manage the existent instabilities (operational risks) efficiently, without considering the occurrence of disruptions; second, these strategies lead to a more resilient supply chain in the case of disruptions.

In order to better explain how robust optimization is applicable to supply chain disruption risks we focus on the concept of resilience. For example, Sheffi and Rice (2005) present the concept of resilient (robust) enterprise. Indeed, resilience can be obtained by building redundancy or reinforcing flexibility. They define redundancy as having slack resources to be used when facing a disruption. They assume that the most common forms of redundancy are safety stocks and dealing with multiple suppliers. In addition, they define flexibility as the organic abilities that can identify threats and react to them immediately. They view five aspects of flexibility which are (1) supply and procurement, (2) conversion, (3) distribution and customer-facing activities, (4) control systems and (5) the right culture.

In order to apply the concept of resilience we also require the definition of a performance index. In the next section we introduce a robust performance index and, by using a weighted approach, we incorporate both risk assessment and risk preference elements in this index.

A Robust Performance Measure for Disruption Risk Management

In the previous section we have defined the concept of robustness as the ability of the firm not to be seriously affected by disruptions (Snyder & Daskin, 2005). In order to measure this robustness we need to create an index. In addition, we also need to find how different risk attitudes can influ- ence optimal policies regarding the performance of a supply chain in the case of disruptions.

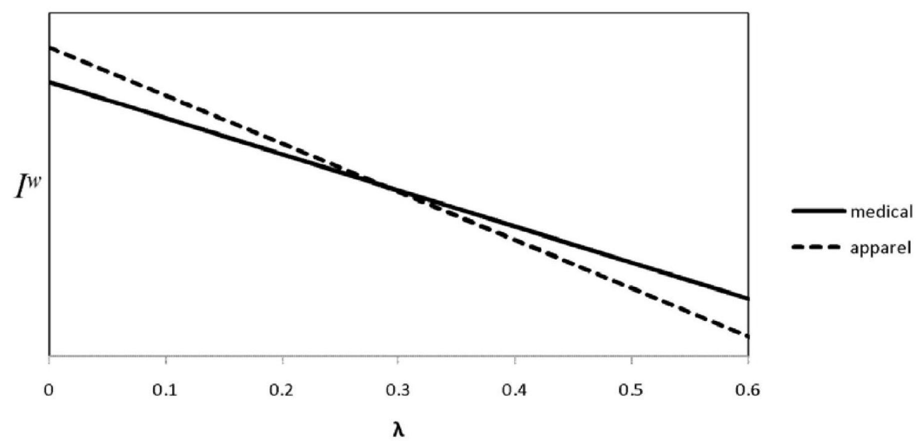
The supply chain performance measure can be an index which determines how the nature of material procurement, transportation of materials, manufacture of product or creation of service, and distribution of product are coordinated in order to satisfy the demand at desired customer service levels (Chopra & Meindl, 2007). Specifically, a supply chain network performs well if, on average, across all demand markets, a large demand can be satisfied efficiently at the lowest price.

Therefore, we suggest the following model which is adapted from Qiang, Nagurney, and Dong (2009) to evaluate the robustness of a supply chain. Due to the fact that estimation of probability disruption p is not accurate, we consider a confidence interval for it which can be shown by $p \in [p_{-}p_{+}]$. Then, we define the supply chain robustness measure, I, as $I = I^o - I^p$, in which I^o evaluates the base supply chain performance or when there is no risk while I^p measures the supply chain performance measure at some predetermined disruption probability level (p) which is included in the confidence interval based on the risk preference of the decision maker. If I is small, the supply chain keeps its normal function in the case of facing disruption with probability p. In addition, the smaller the value of I, the more robust (resilient) the supply chain is.

In order to better explain this intuition about the robustness concept for a supply chain, we provide some examples. We should mention that different industries have different requirements related to supply chain performance and robustness that we introduced before. For instance, for the case of a supply chain of apparel product, one should think how to meet the demand of customers in the most efficient (risk neutral) and not consider much about the supply chain robustness (risk averse). However, in the context of a medical product supply chain, we should have a supply chain which is more robust when faced with disruptions (Qiang et al., 2009). In order to be able to measure and to evaluate the performance of different supply chains with different risk preferences, we define a weighted supply chain performance measure as $I^w = (1-\lambda)I^o + \lambda(-I)$, in which $\lambda \in [0,1]$ is a risk preference parameter which represents the trade-off between risk neutral and risk averse attitudes. Moreover, I^w stands for the weighted supply chain performance measure. In the case of risk-averse attitude, the value of λ is more close to 1 . When λ is equal to 1 , the performance of a supply chain depends only on the robustness measure, which could be the case for a medical supply chain. However, when λ is close or equal to 0 , the performance of the supply chain relies only on how well it can meet demands at lowest prices. Indeed, expected cost has the most important role for decision making (risk neutral). The supply chain of an apparel product could be included in this category.

In order to illustrate this concept, next we compare the weighted robust performance measure for two different supply chains for apparel and medical products with a simple numerical example. We use subscripts a and m for apparel and medical supply chains, respectively. Assume that the risk neutral performance measures are $I_a^o = 0.18$ and $I_m^o = 0.16$ for apparel and medical supply chains, respectively. Indeed, the apparel supply chain has a better risk neutral performance measure (higher) than medical supply chain due to meeting the demand at lower cost. Now, assume that we have a confidence interval for disruption probability $p \in \left[10^{-3}, 10^{-1}\right]$, and in the case of disruption with probability p equal to 0.01 , the new performance measures are $I^p{}_a = 0.11$ and $I^p{}_m = 0.08$. Therefore, the supply chain robustness measures are $I_a = 0.1$ and $I_m = 0.05$. As a result, the medical supply chain is more resilient (robust) in the case of facing disruption since it has a lower value for its robustness measure. So, if we consider a pure risk aversion approach, the medical supply chain performs better than the apparel supply chain when facing disruption.

Figure 5. The weighted performance measure for two different supply chains as a function of risk preference parameter (λ)



Now we consider the interaction between these two risk perceptions with the unified weighted performance measure (I^w). As we can see from Figure 5, by taking into account both factors for risk neutral and robustness (risk aversion), the higher the value of weighted performance measure the better the supply chain performance facing disruption. By changing the value of λ from 0 to 0.3 , the apparel supply chain performs better than medical supply chain. However, by taking into account the values more than 0.3 to 1 , the medical supply performs better. Obviously, for λ equal to 0.3 , the weighted performances are equal.

So, by placing lower weight on λ, or being more risk neutral, as we expected the performance of apparel supply chain is better than medical supply chain. However, by being more risk averse, or increasing the value of λ above 0.3 , the medical supply chain performs better. Obviously, this approach can be generalized for comparing more weighted performance measures and it renders the threshold (λ) for comparing different performance measures of supply chains. In addition, we can compare the weighted performances with a given risk preference (λ). Generally, companies can prepare for disruptions in the supply side by building inventory or by having redundant suppliers due to the fact that it is unlikely that all suppliers would be disrupted simultaneously (Sheffi & Rice, 2005; Chopra & Sodhi, 2004). However, having inventory for managing disruptions can be very costly. The reason is simple: while holding costs are incurred continuously, the inventory would be used only in the rare event of a disruption. Moreover, the company pays (and continues to pay) for reserves that may never be used: as a result, to hold inventory as a hedge against disruption makes sense only for commodity products with low holding costs and no danger of obsolescence. The large petroleum reserve kept by the United Sates is a perfect example of this strategy (Murphy & Oliveira, 2010). So, for the case of commodity products (high-volume products), we can have a robust supply chain by placing more weight in the risk neutral part of weighted performance measure, i.e., I^o.

On the other hand, for products with high holding costs and/or high rate of obsolescence, using redundant suppliers is a better strategy. For instance, Motorola Inc. buys many of its handset components from multiple vendors. Doing so prepares the company for disruptions without building up fast-depreciating inventory. Moreover, Motorola lower the cost of redundancy by using multiple suppliers for high-volume products and single sourcing for low-volume products (Tailored outsourcing). This approach helps company lower the risk of disruption while presenting economies of scale at its suppliers. Therefore, based on our approach due to the context of the industry for Motorala, a risk averse approach makes the supply chain more robust (resilient) and the manager should place more weight on the risk averse part of the performance measure, i.e., I. Robust optimization has also been used in the electricity industry to coordinate the decisions of selling in the futures or spot electricity markets, e.g., Gulpinar and Oliveira (2012).

CONCLUSION AND FUTURE TRENDS

Most studies assume that the disruption probability is as a known parameter. In reality this parameter is very difficult to estimate, due to the fact that such events do not occur regularly. Managers tend to underestimate the disruption probability (or the impact of disruptions) because of its low probability of occurrence.

In this chapter we have discussed the important role of the disruption risk in supply chain management and we have analyzed how robust optimization can be used to manage this risk. More specifically, we have shown how robust optimization can deal with inaccuracy in disruption probability estimates and can take into account the risk preferences of decision makers. We have also discussed why the designing of a robust supply chains is crucial, given the increasing likelihood of catastrophic events (in part potentiated by the globalization process) for improving risk management.

We believe that the future research trends in this area include the development of holistic perfor- mance measures in order to evaluate supply chain performance based on robustness approaches. **R** Moreover, we think that there is a need to further develop empirical work to evaluate supply chain robustness in different industries.

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KEY TERMS AND DEFINITIONS

Disruption Risks: Are the major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, and economic crises such as currency evaluation or strikes in the context of supply chain. In other areas they are mainly known as catastrophic risks.

Performance Metric: Is a measure of an organization's activities and performance. Performance metrics should support a range of stakeholder needs from customers, shareholders to employees. While traditionally many metrics are finance based, inwardly focusing on the performance of the organization, metrics may also focus on the performance against customer requirements and value. Risk Management: Is the identification, assessment, and prioritization of risks (as the effect **R** of uncertainty on objectives, whether positive or negative) followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities.

Risk Perception: Is the subjective judgment that people make about the characteristics and severity of a risk. This concept is most commonly used in reference to natural hazards and man-made disasters like terrorist attacks and strikes.

Risk Preference: Is a concept that explains what one person does when faced with a risky option and a safer alternative; it is an important predictor of one's behaviour under risk.

Robust Optimization Methods: Are applied to account for the risk-averse attitude of corporate decision-makers and to immunize the performance of the firm against the impact of imperfect information

Supply Chain Risk Management: Is the management of supply chain risks through coordination between the supply chain members in order to guarantee profitability and continuity.