SUPPLY CHAIN RISK MODELS

ABSTRACT: *The increasing complexity of the supply chain networks and the strong interdependencies existing between logistics organizations taking place in different business field make supply chains vulnerable to potential disruptions and risks. Environment changes and turbulence, which affect supply chains all over the world, is one of the most important factors influencing the efficiency of the supply networks by increasing the exposure level to risks. As a result, there is an increasing consciousness of the vital importance of developing risk management approaches and strategies across all actors within supply chain networks. Different models have been developed and introduced in the literature to deal and to manage different types of risks within supply chain networks. This article presents an short overview of supply chain risk models. While this review isn't intended to be exhaustive, it provides indicative of different models developed by supply chain management researchers to deal with supply chain risks.*

KEYWORDS: *Supply chain, risk, supply chain risk, risk models.*

1 INTRODUCTION

There is a common consensus about the need to understand the causing factors of supply chain susceptibility to risks and the their occurrence impacts. The attempts to give answers to these basic questions have been the topic of years of research and experiments, resulting in a plethora of tools, methods and practices that deal with different issues related to supply chain risks. The need for an effective approach to manage supply chain risks seems apparent. Pfhol et al. (2011) and Heckmann (2016.b) highlight that the search for a mitigation strategy or solution required first and foremost a clear understanding of what the supply chain risk concept means, which still missing in the literature review. According to Ho et al.(2015), "the real challenge in the field of supply chain risk management is to be able to take advantage of risk through selecting and implementing the right mitigation options (Paul et al., 2017). And to achieve this objective, risk need to be integrate in all related supply chain decisions. Thus most of published frameworks focus on either maintaining the coordination of supply chain through optimisation tools to guarantee the ideal conditions of supply chain functions, or developing recovery and mitigation models to minimize the impacts of risk after it occurrence. However, a scarcity of works have been developed to evaluate the cost between implanting mitigation tools or accepting the impacts of supply chain risks. To evaluate any of these options risk need to be considered as one of supply chain objectives. Interestingly, no study has been found which developed a quantitative recovery for managing sudden production disruption in a supply chain with multiple entities in each stage of the system. Aiming to address this issue, we developed in the paper a multi-objectives supply chain model that consider risk as an objective to optimized. Therefore, in this chapter, we propose in the next section a multi-objectives model of supply chain solved using goal programming tool. As a result, in this chapter, we tried to incorporate the risk into the supply chain model. Using a risk score, an analysis is conducted to enable the company to better understand the potential impacts of any potential disruption to the entire supply chain. The analysis will be done through a multi-criteria model for a global supply chain planning, solved using goal programming. To attain this objective, section 2 will present a short description of the problem. Section 3 details the constraints and the objective that were deployed to model the identified problem. Section 4 presents the solution technique and the methodology used to solve this model.

this model.

2 IMPORTANCE OG MANAGING SUPPLY CHAIN RISKS

During the past decade, there has been a growing interest about supply chain risks, caused by natural disasters such as floods, Tsunami, earthquakes, etc., or by human, intentional or unintended actions such as accidents, terroristic acts, strikes, etc. Such an interest could be explained by the increase of the occurrence and the impacts magnitude of the risks on supply chains around the world. The occurrences of a variety of disruptive events (such as: Hurricane of Sandy (in 2012); the Hurricane of Irma (in 2017); the earthquake or the Tsunami of Japan (in 2011); the flood of Thailand(in 2011); the Arab Spring(in 2011); the Occupy Wall Street movement (in 2011); and many others) have showed how these disruptive events may further influence physical flows of goods and materials within supply chain networks (Simchi-Levi et al., 2014) causing a significant impacts to entire supply chain businesses. For example, in 2003, the sudden outbreak of the Severe Acute Respiratory Syndrome (SARS) reduced the number of travellers in Asia (demand disruption in the touristic supply chain). In 2010, the Iceland volcano Eyjafjallajökull disrupted millions of air passengers in the tourism industry (demand disruption in the airline service supply chain). The Japanese tsunami in 2011 led to the need for the automotive industry to cover over a period of several months (supply disruption in the automotive supply chain). The Rana Plaza Bangladesh factory fire in 2013 greatly influenced orders from international apparel buyers (supply

disruption in the apparel supply chain). All the above real cases show that disruptions may affect the end to end of the supply chains (Stauffer, 2003).
According to the empirical studies by Hendricks and Singhal (2005), supply chain risks could not only significantly and negatively affect firms' shareholder value but they could lead to supply chains insolvency if they weren't able to recover quickly from these risks or disruptions. Thus, every enterprise recognises nowadays the need to define, to avoid or even to mitigate the possible damage of these risks if they occurred within the supply chain networks. However, it's widely recognized that supply chains are becoming more global. They link different international actors using multi-modal transportation network from all over the world. Although that some supply chain networks have implemented different risk management tools and protocols, recent disruptive events have highlighted that risks can exceed the control of one supply chain, to impact the entire network in which supply chain operate. As a result, firms are increasingly recognising for the common need for managing the supply chain risk. Managers start acknowledging that the application of the cost reduction trends to their supply chain operations could increase the exposure level to risks. And this could threaten their performance if not their continuity in the market: "Today, it is critical that enterprises, in addressing emerging supply chain risks, move from being reactionary to being proactive and resilient, knowing that at some point, somehow, and perhaps frequently, your business will be impacted by a supply chain disruption of one form or another." Therefore, developing methods to reach the highest level of efficiency achievement is not the only concern of supply chain managers today, since these methods have started to increase the exposure level to risks. Managers, nowadays, are seeking to achieve a trade-off between increasing profit, eliminating waste and costs and the costs of disruptive risks. Indeed, Zsidisin et al (2004) underline the importance of supply chain risk management and the need to be integrated into the strategic decisions and practices of supply chains. It is imperative not only to identify the overall supply chain costs (arising from supplier, production, inventory, etc.) but also the value of risks when these risks become reality. Thus, it is important to develop an efficient management method with innovative models for identifying, managing, and controlling supply chains in the presence of disruptions. Identifying disruptions means that the firms detect supply chain changes in a certain time period. Managing disruptions refers to the design and the selection of a predesigned solution for reducing disruption effects in a supply chain.

3 SATE OF ART ON SUPPLY CHAIN RISK MODELS

Today's supply chain managers are faced with an increasing challenging task of managing risk in their supply chains. As Hammant and Braithwaith (2004, p. 1) put it: "With supply chain networks becoming ever more global and complex, risk and contingency planning is not simple." When enjoying the benefits of focusing on their core competencies by outsourcing and adopting new business models such as Just-In-Time (JIT) manufacturing, Lean practices, products variants, etc., firms also expose themselves to uncertain events, generally called "risks." To firms, risks in supply chains arise not only from their business partners such as suppliers, but also from customers, internal operations, new technologies, political issues, natural disasters, etc. Some risks can be reduced or even eliminated, but others are hard to control. How to successfully manage the risks in supply chains has become more and more critical to firms. Although a lot of firms have already realized the importance of supply chain risks, few are well prepared because of the complexity of the risk issues in supply chains and the lack of good techniques. A study completed by FM Global indicated that more than one-third of the financial executives and risk managers surveyed do not feel that they are adequately prepared for disruptions to their business. The 2003 Protecting Value showed 34% of respondents rated the extent of their preparation for disruptions to their major source of revenue as fair or poor (Bradford 2003; Attai, 2003; Bilsel, 2009; Bowersox et al., 2002; Chopra & Sodhi, 2004; Cohen & Lee, 1989; Handfield & McCormack, 2008; Kleindorfer & Saad, 2005; Manuj & Mentzer, 2008; Monczka et al., 2011; Portillo, 2009; Yang, 2007; Vidal and Goetschalckx, 1997). Introduction to risk into supply chain models is related to supply and demand fluctuations and uncertainty, delay in scheduling (Hoppe et al.1989). For example, Disney and Towill (2002) develop a linear classical control inventory to analyze the effect of inventory disruption on the selection of inventory policies. Villegas and Smith (2006) follow this line of research and extended it to encompass the fluctuation of demand. Lin et al (2014) focus on the reliability of supply chain under production capacity fluctuations. Ivanov et al (2013) used a multi-structural supply chain models to design production - distribution network with supply disruption. Sawik (2015) develops a robust stochastic programming model under facility and capacity disruption. Other models can be found on all decision making (selection, planning, transportation, etc) to protect supply chain from a particular type of disruption. Ivanov et al (2016), Dolgui et al. (2015), Hamdi et al. (2015), Sawik (2015) and Govindan (2017) present an interesting overview on supply chain models including risk analysis. The review results several frameworks have been published to consider risk in the supply chain models. A sample of different frameworks of supply chain models comprising risk and disruption analysis is presented and categorized in table V.1.

Ref	Objective	Method	Types of risks
Weiss and Rosenthal (1992)	To integrate the disruption in the EOQ[1] inventory model	Stochastic economic order quantity (EOQ) model	Disruption risks

[1] EOQ (Economic order quantity)

Lin (2001)	To determine the production quantity of particular product for a random demand	Deterministic bipartie graph of simplified sc that consists of plants and retailers, solved by a heuristic scheme	Supply disruption
Babich et al. (2004)	Determine optimal timing for supplier payments and optimal wholesale price	A game theoretic model	Supply disruption and incorporated demand uncertainty
Babich (2005)	Theory of financial options	Defer ordering decisions	Uncertainty (Bernoulli theory)
Chopra et al. (2005)	Analyse the quantity to order	Stochastic economic order quantity (EOQ) model	Supply risk and supply disruption risk
Snyder and Daskin (2005.a)	Select facility location	Multi-objective mixed integer program solved the model through a lagrangian relaxation algorithm	Disruption risks
Snyder and Daskin (2005.b)	To find an optimal SC design with assignments of customers to locations with the objective to minimize total SC costs	Mixed-integer programming	Disruption
Hopp and Yin (2006)	Analyzed effects of protection policies to mitigate disruption risks for service supply chain	Nonlinear mixed integer programming	Supply disruption
Snyder and Shen (2006a)	To determine optimal the optimal order quantity	Simulation	Demand uncertainty and supply risk
Tomlin (2006)	Supplier selection	Stochastic optimization	Supply disruption
Wu et al (2006)	Risk classification	AHP + linear programming	Supply chain risk
Xiao and Yu (2006)	Profit maximization and revenue maximization	Game theory approach	The effect of supply disruption on retailers in a supply chain
Azaron et al. (2008)	To develop a multi-objective stochastic programming approach for supply chain design under uncertainty.		
Qi, L., Shen, Z. J. M., & Snyder, L. V. (2010)	Determines the locations of retailers and the assignments of customers to retailers in order to minimize the expected costs of location, transportation, and inventor	A nonlinear integer programming mode	supply disruptions
Lim et al. (2010)	To improve SC design decision under the disruption	Mixed-integer programming	Supplier destroy
Iakovou et al. (2010)	To capture the trade-off between inventory policies and disruption risks	Single period stochastic inventory model	Unreliable supply ynder capacity variation
Vahdani et al. (2011)	To calculate the completion time of SC operation in the presence of risks	Fuzzy theory	Disruption
Chou et al. (2011)	Ro determine systems reliability achieving a given deterministic demand	Algorithm without a profit/cost function	Node failure
Atan, Z., & Snyder, L. V (2012)	Find optimal management of inventory systems subject to supply disruptions	Economic order quantity (eoq) model	Supply disruptions
Losada et al. (2012)	Protecting an incapacitated median type facility network against worst-case losses, To evaluate the facility recovery time under different disruption	Bi-level MIP	Multiple disruption
Costantino et al (2012)	To develop an hierarchical supply chain dsign and planning to improve SC agility in terms of reconfigurations to meet certain performance level,	Diagraph modelling and integer LP	Disruption risks
Schmit and Singh (2012)	To estimate and to quantify the disruption of risk at production and supply capacities in a multi echelon supply chain	Discrete event simulation	Disruption risks
Cavalho et al. (2012)	To analyze the impacts of transportation disruption on lead time and overall costs in automotive SC	Arena based simulation	Transportation disruption
Rafiei et al. (2013)	Test different response plans (back-ordering, available machine capacity and labour levels for each source, transportation capacity)	Genetic algorithm	Disruption facility
Choi (2013)	Model to SC risk analysis in retail industry	Mean-risk model	
Markmann et al, (2013)	S to gauge to what degree the Delphi technique can support and improve risk analysis.	Delphi techniques	Man-made risks
Sawik (2013)	Supplier selection order allocation and customer order scheduling	Stochastic programming	Disruption risks
Hishamuddin et al. (2013)	Develop a recovery model for a two echelon serial SC with disruption consideration to determine the optimal ordering and production quantities during the recovery period to minimize total risks		Transportation disruption

Gedik et al. (2014)	Assess impacts of disruptions in terms of transportation and delay costs	Two-stage mip model.	
Madadi et al. (2014)	Supply chain design	Mixed integer stochastic model solved by met heuristic algorithm	Supply disruption
Xu et al (2014)	To study supply disruption and recovery policies at the SC service	Multi agent theory (any logic software)	Supply disruption
Paul et al.(2014)	To analyze the impacts of series of disruptions and to develop an optimal recovery policies	Two-stage production-inventory model	Disruptions
Käki, A., Salo, A., & Talluri, S. (2014)	Develop a methodology for analyzing risks caused by supplier disruption	Probabilistic risk assessment (pra) + complex engineering system	supplier disruption
Torabi et al (2014)	Supplier selection and allocation problem	Bi-objective mixed two stage stochastic model	Operational and disruption risk
Gupta et al (2014)	To analyze the implications of the contingent sourcing strategy under the supply disruption	Game theory approach	Supply disruption
Levi et al (2015)	To develop a new model to analyze operational - disruptions risk		Operational - disruptions risk
Nooraie & Parast (2015)	To develop a multi-objective decision model to evaluate the interactions and dynamics among SCV and SCR as well as supply chain cost for new products with probabilistic demand.	NP-hard mode solved by an heuristic algorithm and expected value method	Demand and supply risks
Sawick (2015)	To select suppliers and to schedule the production and distribution in a multi-echelon supply chain subject to local and regional disruption risks	Bi-objective stochastic mixed integer programming	Disruption risk
Torabi et al. (2015)	Supplier selection and order allocation problem	Bi-objective mixed two-stage stochastic programming model	operational and disruption risks
Simchi-Levi et al.(2016)	To analyze the Risk Exposure Index (REI) and to measure supply chain resiliency by analyzing the Worst-case C-VAR (WCVAR) of total lost sales under disruptions.	A Bi objective model	
Ivanov et al. (2016)	Propose a new approach with an explicit connection of performance impact assessment and supply chain plan reconfiguration issues with consideration of the duration of disruptions and the costs of recovery	A stochastic mixed integer programming	Disruption risks
Sawick (2016)	To optimize lower tail performances in supply chain risk management	A stochastic mixed integer programming	Disruption risk measured cvar
Ransikarbum and Mason (2016)	To investigate strategic supply distribution and early-stage network restoration decisions.	Goal programming-based multiple-objective integrated response and recovery model	Supply risk (probability theory)
Sawik (2017)	To study the integrated decision making to simultaneously select suppliers of parts and schedule production and delivery of finished products to customers in a supply chain under risks	A bi-objective stochastic mixed integer programming approach (minimization of cost and maximization of service level)	Supply risk (probability theory)
Paul et al. (2017.b)	To minimize the total production costs under the transportation disruption	Stochastic economic order quantity (EOQ) model	Transportation risks

Table1 : Supply chain models considering risk analysis

As it can be seen from Table 1, several models developed to manage supply chain including risk analysis. These models can be classified into:

- Basing on the modelling approach: two main categories can be distinguished: the first one is the deterministic approach and the second one is the stochastic approach. The main difference between these approaches relies on the type of input and output for each approach. For the first one, the output is the determined by the parameter values under initial predefined conditions. Where, in the second one, a random variables are deployed to model the uncertainty about model inputs and outputs (Lee 2014).
- Basing on objective: two main classes can be found: The single, the bi-objective and the multi-objective.
- Basing on decision variables.
- Types and the emplacement of risk considered in the model

However, few consider risk as a decision variable. Most of the developed models are oriented towards cost reduction, profit maximization or customer satisfaction.

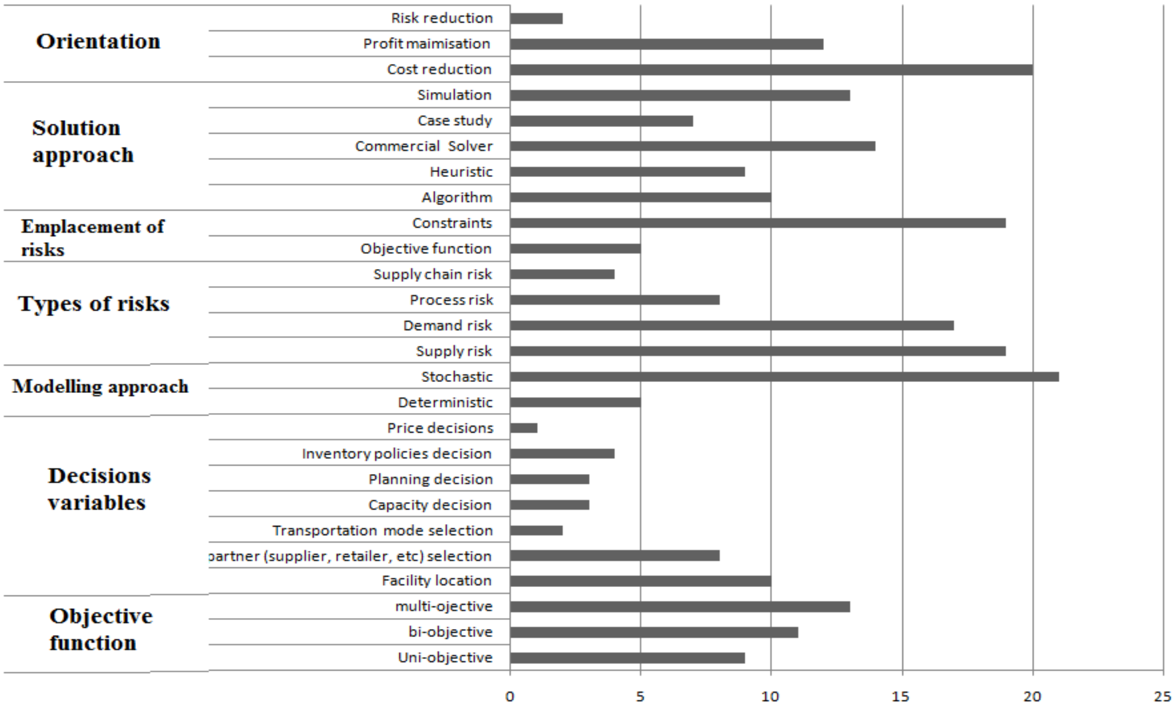

Figure 1 Classification results of supply chain models incorporating risk analysis[2]

However, with the increasing number of risk events, it becomes critical that enterprises, to move from being reactionary to being proactive and resilient. Knowing that at some point, somehow, and perhaps frequently, your business will be impacted by a supply chain disruption of one form or another."(Paul et al., 2017b) Therefore, developing methods to reach the highest level of efficiency achievement is not the only concern of supply chain managers today, since these methods have started to increase the exposure level to risks. Managers, nowadays, are seeking to achieve a trade-off between increasing profit, eliminating waste and costs and the costs of disruptive risks. Indeed, Zsidisin et al (2004) underline the importance of supply chain risk management and the need to be integrated into the strategic decisions and practices of supply chains. It is imperative not only to identify the overall supply chain costs (arising from supplier, production, inventory, etc.) but also the value of risks when these risks become reality. Thus, it is important to develop an efficient supply chain models to consider risk concept.

Basing on the results found in Table 1, there are some models that consider risk in their mathematical functions. However, considering risk as a cost variance does not give the overall picture of the supply chain risk impact on supply chain continuity and performance. Therefore, it is necessary to introduce a new objective function to clearly capture the risk notion. This will be implies adopting the approach of multi-objective, as cost and risk are considered as a conflict criteria. However, it is a difficult and challenging task.

4 CONCLUSION

In the above sections, we have concisely examined SCRM papers published within the last period. In summary, table 1 provides the essential characteristics of the papers reviewed in this article. In particular, we highlight the specific areas, objective functions, risk placement and types associated with the papers. A closer examination of reviewed papers reveal that the most of developed models focus only on minimizing cost and maximizing profit as well as net present value and risk is either consider as a constraint to avoid or a parameter to minimise to reach the desired objective. We observed that stochastic models dominated the deterministic approaches where risk and uncertainty are considered as synonyms. This is in conflict with the tendency research in supply chain risk definition and conceptualisation.

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[2] The data used in this figure are extracted from the framework of Lahmar et al.2016, Ho et al. (2015) Govindan et al. (2017) and Ghamari and Irohora

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