Visualization and Quantification of Supply Chain Risks for Global Retailers and Manufacturers

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***Abstract*—A retailer with global presence must have a healthy, robust supply chain. Towards this end, the retailer must develop a good plan to quantify significant supply chain risks and build appropriate mitigation resources. The goal of this study is to identify, quantify, and visualize potential risks to a global retailers supply chain network and recommend better mitigation tools. To achieve this desired outcome, this paper combines network science and operations research methodologies. It builds a simplified decision-making model, where the risk factors of a global supply chain could be perceived as a network with nodes in which the value-at-risk and location are associated with each node. A unique value-at-risk exists at each node in the supply chain. Value-at-risk in our model represents the product of the risk exposure index and the probability of annual loss for the node. A preliminary review of available literature shows good prospects in terms of application to similar problems in this area of research.**

***Index Terms*—Global supply chain risk, network science, and OR approach.**

I. Introduction

Globalization is extending local supply chain across boundaries to accommodate customers demands throughout the world. It has created a connected economic environment unlocking new markets and bringing new customers onboard. It has dramatically changed the business operations opening doors for better opportunities. However, the associated risks are significantly growing with an increased level of globalization. For instance, the number of natural disasters affecting the commerce has only been drastically increasing over the past few decades [1]. These repetitive and large occurrences of natural disasters and huge economic fluctuations disrupt the supply chain operations. Identifying the relevant major risks and addressing them with a suitable mitigation strategy will provide the companies with an added advantage to compete and survive in this ever-growing competitive global market. Supply chains are invariably exposed to a multitude of challenges that prime the companies to expanded their capabilities to mitigate the overall impact. Supply chain managers need to make well-informed decisions to make the best of the opportunities and design strategies to hedge these unexpected uncertainties. Uncertainties and related risks are inevitable in supply chain/web, nevertheless, efficient risk management and readiness to handle the unseen situation is vital to outlive in the growing market. As there is no silver-bullet strategy to shield against all the risks, executives need to make necessary trade-offs to mitigate and prioritize major risks.

II. Literature Review

[4] the study investigates the effect on the equity risk and stock prices due to the supply chain disruption for the period of 1989-2000. Equity risk and stock price further impact the various stakeholders i.e. investors, supplier, employees, management board and mainly the customers. The paper quantifies the economic risk of the firm due to any supply chain disruption and the long-term stock price effect. It justifies that the investments made in increasing responsiveness and reliability of the supply chain to establish a mitigation strategy that improves the real-time visibility, anticipating disruptions and related effects.
[5], the paper explores the use of integrated approach in handling supply chain risks such as the use of (r,Q) policy for inventory management and choosing a suitable location for the inventory, using a linear integer programming and algorithm to study the probability of a supply chain disruption etc. The study uses a Lagranian Relaxation approach to study the disruption and response probability and quantifies the related economic losses for a dynamically sourced supply chain design to capture and study the impact of risk pooling and risk diversification. It justifies that studying the probability of disruptions and improved preparedness reduces the threat cause by the supply chain disruptions.
[3], the paper discusses various methods of building a resilient supply chain to address the vulnerability of supply chain in todays market by developing proper management and mitigation strategy. The effects of several strategies such as mapping, sourcing decision, efficiency vs. redundancy tradeoff, collaborative planning, creating a supply chain risk management culture in workplaces, creating visibility of the risks etc. is discussed in order to develop a robust action plan.

[8], the article explores an initiative to study the risk and vulnerability associated with globalizing supply chain and transport network for the year 2012. As these (globalization and transportation) form the pillar of the global economy today, the impact of the associated risks is devastating resulting in huge financial losses. The article further discusses the results of the workshops conducted in different parts of the world to deepen the problem understanding and identify the risk landscape. Effect of natural disasters, political factors, terrorism, geopolitical restrictions, supply-demand variation

etc. is studied and suitable solutions to fight the volatility is analyzed.

III. Problem Statement

Global and local supply chains are constantly subjected to numerous risks as they expand geographically and operationally. Certain risks can cause major and irrecoverable disruption to the supply chain and the intensity of disruption depends on the source and nature of the risks. In order to focus on the risks causing catastrophic impact, companies need appropriate tools to identify, quantify and model the risk factors. Even so, quantifying the supply chain risks merely indicate the degree of impact, comprehensive and powerful tool to quantify and visualize the major risks in the different locations is the need of the hour.

IV. Geographical Scope

A. Facility Sites/Location

I illustrates the locations analyzed in our simulation with associated risks.

TABLE I
Risk Location List

Selected Global Risk Locations		
Loc. Name	Loc. Name	Loc. Name
Buenos Aires	Salvador	Arteixo
Paris	Mumbai	Montreal
Melbourne	Mexico City	Ankara
Saint Petersburg	Tijuana	Monterrey
Abidjan	Casablanca	Roma
Nairobi	Istanbul	Porto

V. Types of Risks

II shows the various types of the risks sampled for this study.

TABLE II
Types of Risks

Selected Types of Risks			
Financial	Harzardous	Strategic	Operational
Credit default	Natural disasters	New technology	Suppliers issues
Interest rate fluctuations	Wildfire/Tornado	New competition	Cyber attack
Fuel prices	Missing Cargoes	Change in demand	Theft of resources
Tax laws changes	Building fire	Negative media	Loss of key personnel
Economic Recessions	Product liability	Ethic violation	Logistic issues
Liquidity/Cash	Facility loss	Technologies choices	Health/safety violations

VI. Impact & Consequences of Risks

1 shows a summary of this factors.

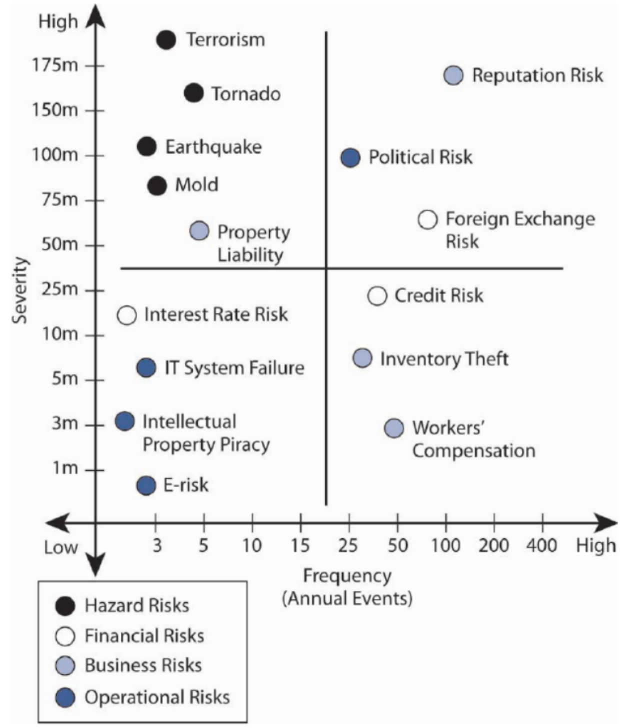


Fig. 1. Impacts/Consequences of Risks

VII. Methodology

A. Mathematical Model and Analysis

Assuming that the company has manufacturing facilities at locations named Nm (generally, $N_m \leqslant 25$ which include warehouses and distribution centers) and number of stores Ns (for a globally present company, usually $N_s \geqslant 1000$ locations). Hence, the total number of locations is as given below: $Nm + Ns = N$

1) Assumption Underlying Model: The following are some of the assumptions underlying our mathematical modeling adopted in this study.

- Aggregate probability of experiencing a loss for the company at any given place in the supply chain is derived from the same distribution or process. The company is less likely to open a location if it is subjected to higher risks (financially or weather wise or any type of associated risks) compared to its current locations.
- Global presence is a gradual phenomenon based on extensive research. Hence, companys historical data is used to estimate the parameters of the distribution or the process that are derived from the supply chain modeling.
- Time series data from the company are used to record the number of major issues at a particular location and its corresponding impact on the location. Further, the time to recovery and other useful metrics are calculated.

2) Modeling the Time & the Type of Events in the Supply Chain Using Markov Chain: Suffice to mention that the major contribution of this work to the existing literature of the topic is the attempt to model the global supply risk as a Markov Chain are illustrated below.

Various techniques are available to model the supply chain. In this research, Markov chain modeling is implemented. Consider that the locations open and join the supply chain according to a Poisson process at a rate v (rate is estimated based on the companys past data). Each location remains joined to the supply chain (without disruption) for a specific amount of time which is exponentially distributed with rate and then get disrupted (major disruption). Independently, each location is subjected to an impact due to the issues and other risks according to a Poisson process at a rate of λ.

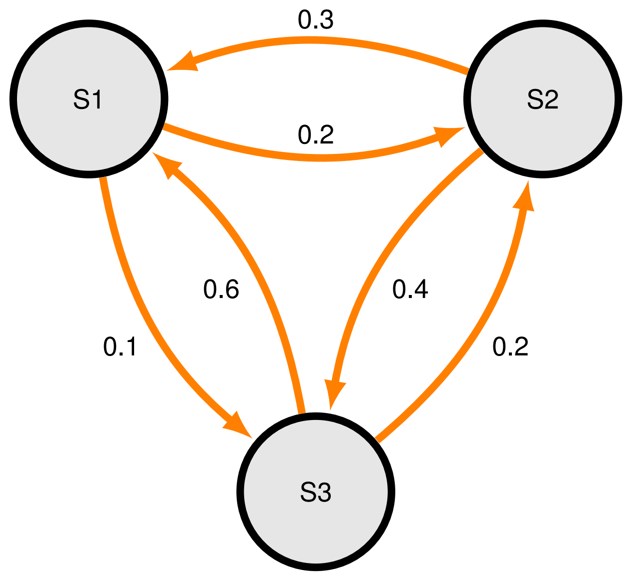
All impact sizes are independent and identically distributed with the same distribution (estimated based on the historical data). Revenue generated at each location is c per unit time. At any given time t, the number of locations $N = N_m + N_s$. Let the random variable X_1 denote the time until a new location is open, X_2 denote the time until the current location experiences a major disruption, and X_3 denote the time when there is a negative impact or effect on the entire chain value. Then, by the Poisson/exponential assumptions of memoryless property of the exponential distribution, these 3 random variables are independent and exponentially distributed:

$$X_1 \sim \exp(v)$$

$$X_2 \sim \exp(N\mu)$$

$$X_3 \sim \exp(N\lambda)$$

X_1:Time until the next event from the Poisson rate v process. X_2:represents N locations, each independently with their own opening (joining) time " $Y_1, ..., Y_N$ exponential at rate . Thus $X_2 = minY_1, ..., Y_N$, which is exponential at rate $N\mu$ because $P(X_2 > x) = P(Y_1 > x, ..., Y_N > x) = P(Y > x)^N = exp(\neg N\mu x)$. Similar to X_2, $X_3 \sim \exp(N\lambda)$ as it is the minimum of N iid $exp(\lambda)$. Hence supply chain behavior overtime can be modelled as a Markov chain with 3 types of events as follows:
S_1: a new store (location open) S_2: an existing store or locations close (disrupted) as a result of a catastrophic event S_3: an impact (loss) is recorded (or comes in) on the company value or return.



The time until the next event is the minimum m = min X_1, X_2, X_3, hence is itself exponentially distributed with rate $r = v + N\mu + N\lambda$ which is the sum of the three rates. Thus, if the current time is t and there are N locations, then next event can be predicted at time $t + (-(1/r)ln(U), (0 < U < 1)$
To determine the type of event: Noting that each of X_1, X_2 or X_3 will be the minimum with probabilities $p_1 = v/r$, $p_2 = N\mu/r$, $p_3 = N\lambda/r$, independently generate a random variable C with distribution $P(C = 1) = p_1$, $P(C = 2) = p - 2$, $P(C = 3) = p_3$; if $C = i$ it implies that the event is of type S_i. We therefore generate U.
If $U <= p_1$,then set $C = 1$. If $p_1 < U <= p_1 + p_2$, then set $C = 2$. If $U > p_1 + p_2$, then set $C = 3$.

B. Modeling the Total Risk on the Chain Using Aggregate Loss

Aggregate loss is the total amount of loss in one period. It can be modelled as follows:

- Individual risk model
- Collective risk model

In individual risk model, aggregate loss is defined by $S = X_1 + ... + X_n$ where the risks(losses) $X_1, ..., X_n$ are stochastically independent. The number of locations is denoted as n and X_i is the impact size for the location i. There is positive chance that the location i will not have any impact in the period of study $P(X_i = 0) > 0$.
In collective risk model, aggregate loss is defined by $S = X_1 + ... + X_N$ where the risks(losses) $X_1, X_2, ...$ are stochastically independent and identically distributed (i.i.d.) and where N is a discrete random variable (called frequency) indicating the number of risks (losses), and that the $X_i s$ are independent of N. The number of impacts is denoted as N and X_i denotes the i-th amount of the impact that has occurred. The distribution of N is called the primary distribution and the common distribution of $X_i s$ is called the secondary distribution. This model is a special case of compound distribution in which random number of identically distributed random variables are added. In collective model,

$P(X_i = 0) = 0$, For $N = 0$; $S = 0$.
If M is the total number of incidents on the supply over a defined period T, based on the data, the probability of incidences at location i is obtained by the following equation:

$$p_i = \frac{\text{total incidence at location 'i'}}{\text{total incidence in the supply chain}}$$

VIII. Results & Discussion

A. Simulation

TABLE III
SAMPLED RESULTS FROM MARKOV SIMULATION

Numerical Results from Markov Simulation			
Event	Time	Event Type	Probability of Occurrence
Next Event	0.1191249	It's a loss being recorded in the chain	0.2800
**	0.1289076	It's a loss being recorded in the chain	0.2800
**	0.1360933	It's a loss being recorded in the chain	0.2800
**	0.1415372	It's location's disruption	0.7000
**	0.1429596	It's location's disruption	0.6977
**	0.1575537	It's a loss being recorded in the chain	0.1760
**	0.6944444	It's a new location joining the chain	0.1950

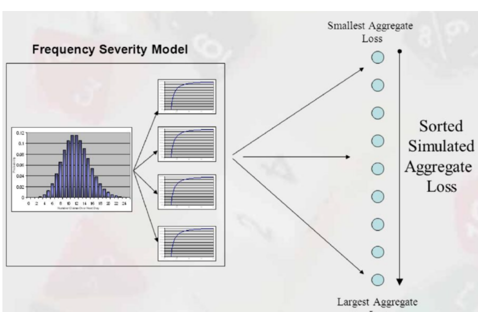


Fig. 2. Sorted Simulation Values

1) Visualization:

IX. Conclusion & Recommendations

The results (5) clearly indicate as to how simulation and visualization can be used as a tool for risk identification and assessment, likelihood of occurrence and impact of the supply chain risks. It is imperative to establish a baseline, analyze the probability and related impact of the risk. For all the leading companies in todays market adaption of advanced tools such as visualization helps in prioritizing risks by the

TABLE IV
RISK LOCATIONS BY CATEGORY

Risks & Categories		
High Risk Loc.	Medium Risk Loc.	Low Risk Loc.
Buenos Aires	Tijuana	Ankara
Paris	Casablanca	Monterrey
Melbourne	Istanbul	Roma
Saint Petersburg	Arteixo	Porto
Abidjan	Montreal	
Nairobi	Istanbul	
Salvador		
Mumbai		
Mexico City		

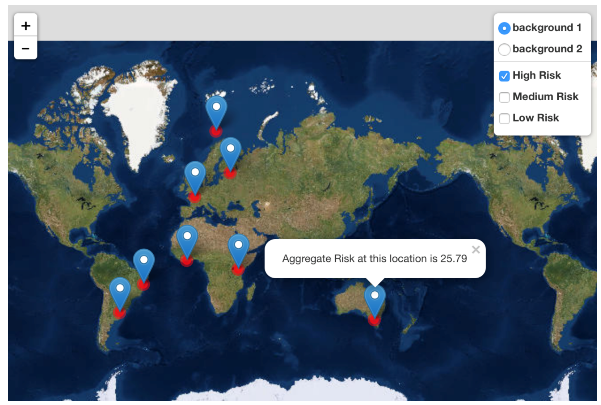


Fig. 3. Location By Categories

threat (based on analysis), bolster the supply chain resilience i.e. having a robust mitigation plan in place.

Supply chain risk mitigation strategy framework begins with use of advanced tools to identify and quantify the risks followed by taking a holistic view of the operating units in the supply chain and ensure the risk factors are accurately prioritized and a strategy is built to overcome these risks.

The major factors involved in the supply chain risk mitigation strategy are shown in 6.

- Framework to mitigate risks
- It is possible to model and simulate the system with a

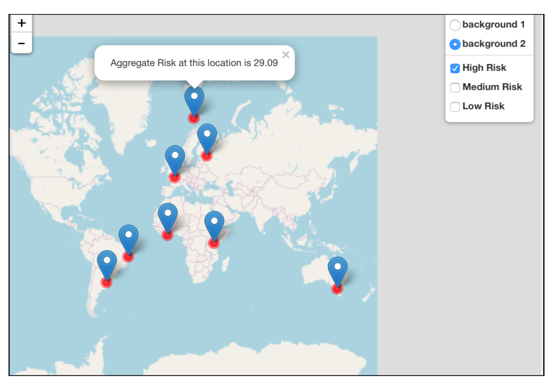


Fig. 4. Aggregate Risk By Location

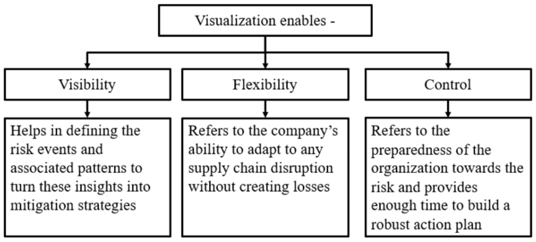


Fig. 5. Summary Chart of Risk Identification & Assessment

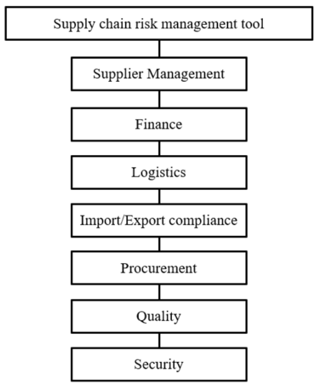


Fig. 6. Major factors to be considered while developing a supply chain risk mitigation strategy

Markov Process

- Visualization is powerful tool in decision-making
- Choose financially strong, competent world-class suppliers.
- compressing global shipping time and cycle time variation.
- Track global shipments and take action promptly

X. Future Work

- Markov chain analysis could be expanded
- Parameter estimation of risk and impacts
- Build an interactive software
- Extensive empirical study
- Performance measurement and accuracy

APPENDIX

We show here the code listing:

ACKNOWLEDGMENT

The preferred spelling of the word acknowledgment in America is without an e after the g. Avoid the stilted expression, One of us (R. B. G.) thanks . . . Instead, try R. B. G. thanks. Put sponsor acknowledgments in the unnumbered footnote on the first page. References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

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