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Networked Supply Chains - Addressing 11 Challenges in Robustness and Resilience

Volume 14-Mar-RISK

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NETWORKED SUPPLY CHAINS
– ADDRESSING 11 CHALLENGES IN
ROBUSTNESS AND RESILIENCE

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Networked Supply Chains: Robustness & Resilience

27th MARCH 2014

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INTRODUCTION

Supply chain risk management has stayed at the top of the corporate agenda, given the propensity for an ever-increasing number of disasters and disruptions to business in the past decade. It is imperative that a company should understand its disruption profile prior to or at least upon a risk event, the available disruption reduction levers for mitigation, and the efficient and effective ways supply chain risk management can contribute to cost avoidance. Compounding the situation is that supply chains intersect other supply chains, sharing resources and members (nodes), in complex patterns.

This white paper documents the progress of research in Phase 1 of a multi-institution study of supply chain risks, their identification and propagation, and the subsequent visualization and monitoring. The intent is to solicit active industry discussion leading to a deeper collaborative engagement in the understanding and resolution of the challenges in building robust and resilient networked supply chains.

Generally, after the occurrence of a risk event, the disruption profile of the risk-prone company can undergo two stages: decay and recovery (red line) (Figure 1).

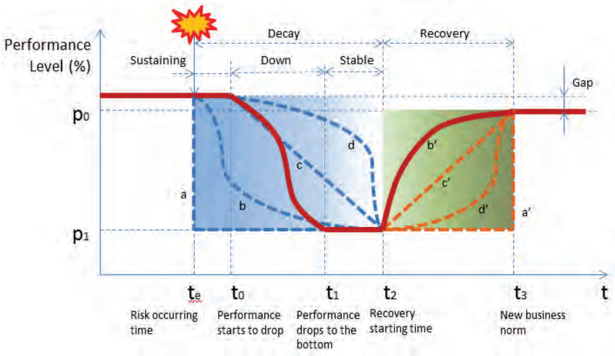


Figure 1. Disruption profile - generic decay and recovery curve

The decay stage shows a company's robustness limit upon the onset of a risk event while the recovery stage shows its resiliency in performance reaching towards its original level. Figure 2 illustrates the disruption profile of a higher robust and resilient company. On the contrary, Figure 3 reveals that a company is fragile in facing a disaster but more resilient in recovering from the disruption.

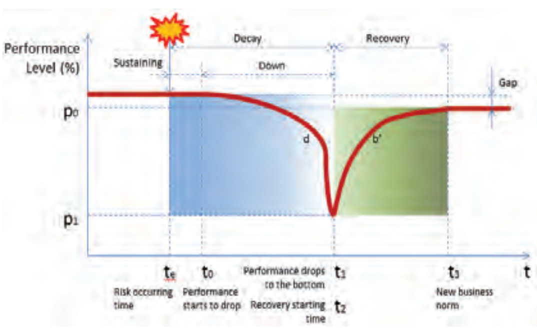


Figure 2. Disruption profile of high robustness and low resiliency

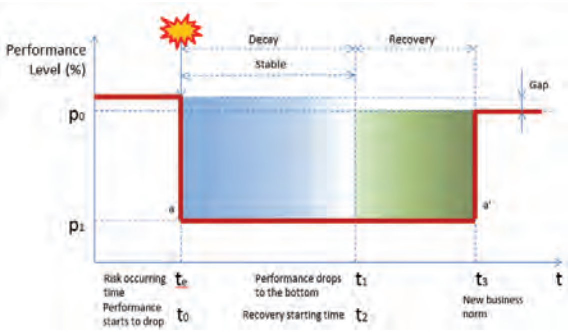


Figure 3. Disruption profile of low robustness and high resiliency

Robustness is defined as the ability of the supply chain (or its entity) to withstand a disruption without adapting its initial stable configuration and **Resiliency** is the property that enables a supply chain to resume its original shape or position after being disrupted. In previous white papers, we presented a series of levers that could be unilaterally or multi-laterally applied according to the generic decay and recovery pattern evident or anticipated. Essentially, there are four disruption reduction levers (Figure 4): act to either delay the disruption impact (1), or act to reduce the disruption duration (2), or speed up the recovery (3), and contain as far as possible the disruption severity (4). One or more of these levers is necessarily engaged for a strategic response.

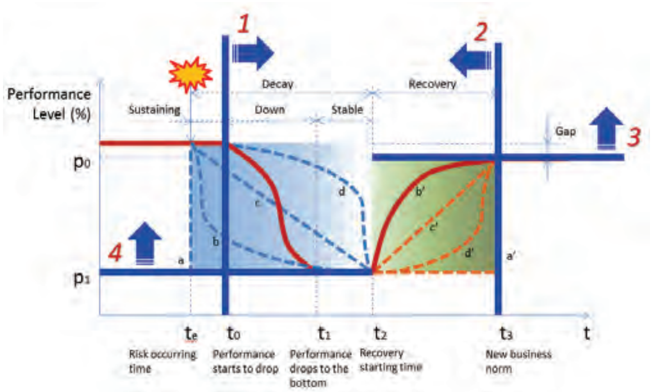


Figure 4. Four possible disruption reduction levers

Though an understanding of the disruption profile is key, just as important is a methodological response. In order to manage supply chain risks, a company should thus be able to systematically identify potential risks/disruptions embedded in its supply chain, assess their impacts, build in mid- or long-term preparedness or mitigation strategies, and monitor risks.

Figure 5. Four phases in supply chain risk management

In the rest of the white paper, we present two approaches for risk identification, three methods for risk assessment and analysis, three strategies for risk mitigation, one platform for risk monitoring, and a master facilitative control tower to support the overall supply chain risk management. Each of the work is presented as a challenge with a problem description, a solution approach, and some results from research to date.

I. RISK IDENTIFICATION

In order to enable companies to systematically identify potential risks in their supply chains, a hierarchical risk framework is developed to guide the risk identification process. The following risk framework considers three levels of risk factors: those arising from within one supply chain, those impacting an industry, and those emanating from macro level events such as natural disasters (Figure 6).

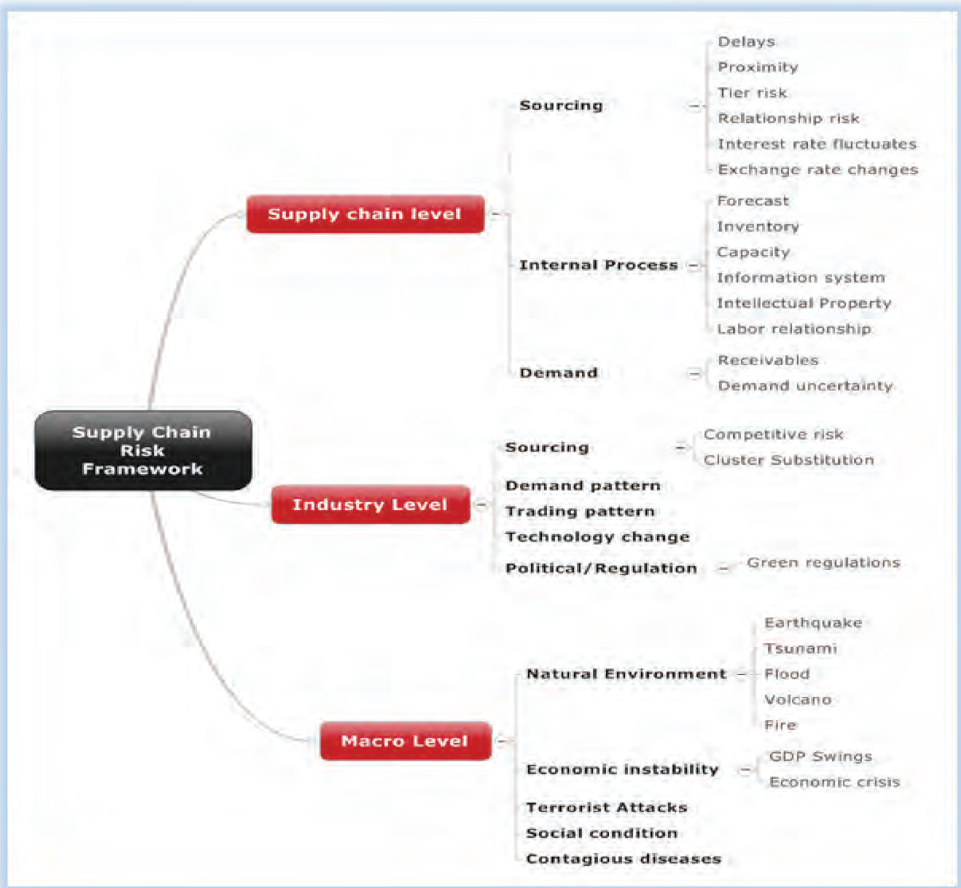


Figure 6. Supply chain risk framework

Challenge 1 – Selection of (alternative) supply chain partners in the event of a disruption

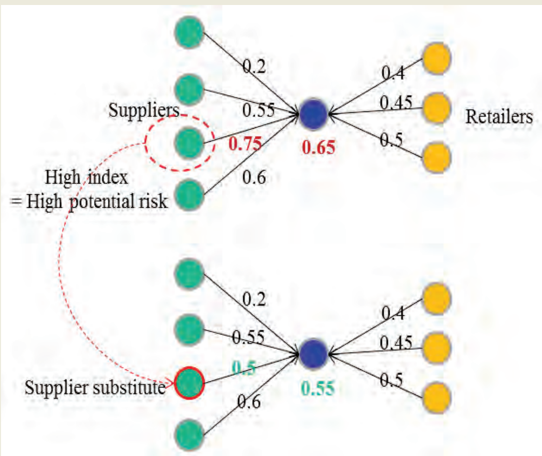
Problem description: It is important for a firm to understand its risk exposure level within the supply chain and that contributed by its partners so that it can choose (1) the best partners before any risk actually occurs and (2) alternative partners post-disruption, without compromising or necessarily increasing the network's *risk exposure index*.

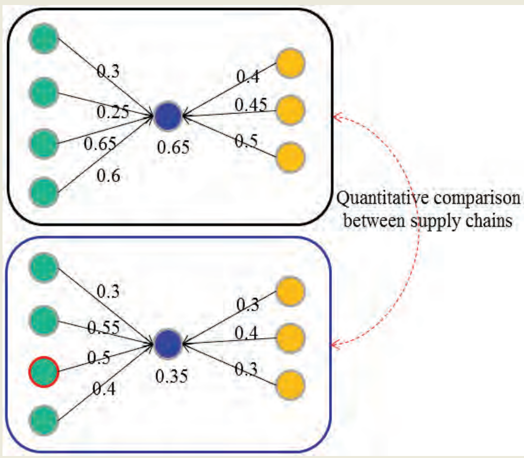
Solution approach: Considering the business environment and activities of a supply chain member, the risk identification framework categorizes and assesses the supply chain risks. We postulate a methodology for determining a risk exposure index for the supply chain as a whole as well as its constituents. Such an approach would be applicable to a comprehensive strategic supply chain diagnosis in view of risk-averse/prone members. Below, are two of the main features of the framework.

- ***Identifying risk parameters***
  Firstly, we need to identify the risk parameters, which can possibly lead to performance disruption. These risk parameters would be defined upon the selection of the key performance measures. It suggests that different performance measures may have different sets of parameters.

- ***Diagnosing supply chains***
  Secondly, the proposed framework measures the degree of supply chain risk exposure on a focal company as well as the interaction activity between the focal company and each of its partners, the degree of risk exposure on the focal company can, in turn, be extended to the entire supply chain (network). Thus, the corresponding supply chain is possibly diagnosed for risk exposure in view of the disruption faced.

Results: With the assessment of risk exposure of its supply chain, a firm can now more confidently determine both, its operational levers and the interaction levels of activities with its partners so that the potential risk exposure would be managed in advance, pre- and post-disruption.



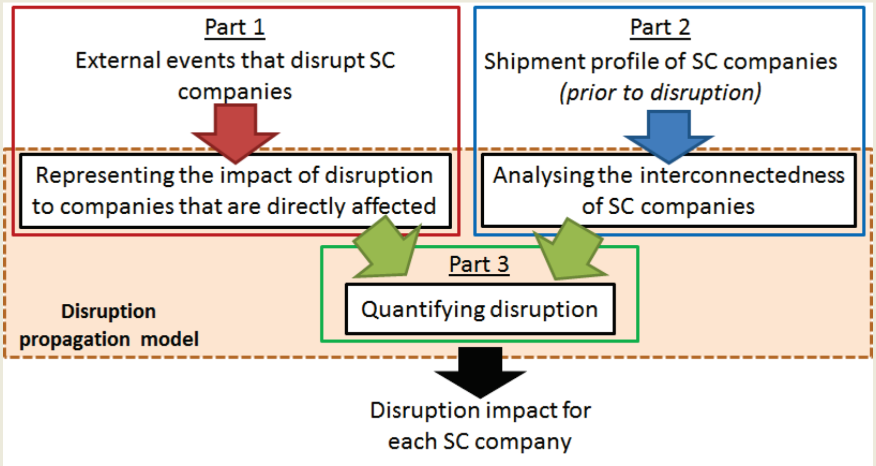


Challenge 2 – How (fast) does a risk event propagate down a supply chain? Can it be characterized, visualized and quantified?

Problem description: Today's supply chains are highly interconnected and a disruption at one company (node) can propagate to other companies in an unexpected manner. It is a big challenge to analyze the propagation of risk along the supply chain effectively, especially on how to quantify the propagation of the risk in a supply chain network.

Solution approach: We developed a time-based model which can be used to quantify the impact of the risk along the supply chain – it provides the visibility of risk propagation. The approach can be used to calculate the propagation index of a supplier's node propagation impact to a downstream node, it can also be used to calculate the propagation impact of that node to next stage customers.

To better evaluate and analyze the different disruption risks present in a complex supply chain network, the disruption propagation model is divided into 3 parts as shown in the diagram below.



- Part 1 consists of an understanding and representation of the disruptive impact on companies that are directly affected. Here, a first assessment of the impact of external disruptive events is undertaken. Based on an initial assessment, the impact may be represented as a change in some of the operating parameters, and the duration of the change that persists. For example, in the event of a port closure, we can assess and estimate the severity of the impact on affected companies by specifying the duration of the event and the shipment quantity that is affected.

- Part 2 consists of studying the interconnectedness between supply chain companies (nodes) in the face of a disruption. The interconnectedness is derived based on: 1) the extension of the interdependency term in the Leontief input output model and 2) the shipment profile of the network prior to disruption.

- Part 3 uses the inputs from the first and second parts to quantify the impact of disruption that directly affects companies or/ and as a result propagates and impacts other SC companies.

Results: The propagation model serves as an analysis tool, which companies can use to identify critical nodes/companies where mitigation strategies can be applied with a high degree of effectiveness. The output of the disruption propagation model shows the duration and the magnitude of the disruption impact on each company.

II. RISK ASSESSMENT

Supply chain risk assessment helps a company to understand the potential risks and their consequences so that it can prioritize resources for risk mitigation and management. In assessing the impact of certain disruptions to a company or a supply chain or a network, we propose a what-if and the Value at Risk approach for investigative analysis.

Challenge 3 – Can preparedness be enhanced through what-if analysis of robustness?

Problem description: It is generally difficult for a supply chain company or node to identify its exposure to critical risks, the origins of these risks, as well as their magnitude of impact. When a risk hits, the company may face difficulty in maintaining its service level and productivity if a pre-disruption robustness assessment is not undertaken. Thus, it is valuable for a company to systematically *what-if* the potential risks embedded in its supply chain.

Solution approach: The risk assessment starts with a supply chain mapping process to define the scope and pinpoint the location of the focal company. Then the risk framework is adopted to guide the process of identifying potential risks and a simulation model is used to provide quantitative assessment of impacts caused by a risk event. Through systematically designed scenarios, a company can thus identify its major potential vulnerabilities. Further, the tool can be used to test proposed mitigation strategies and evaluate the risk impacts in terms of service level, inventory cost, and lead time.

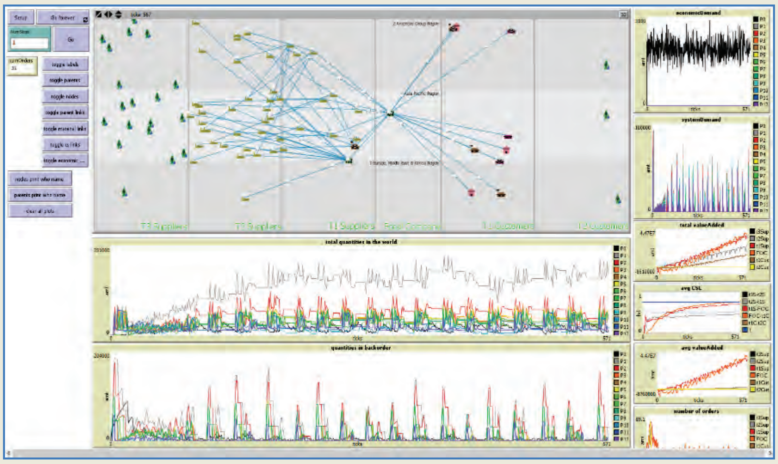
Results: A simulation tool has been built and supply chain elements such as customer, retailer, distribution center, manufacturer, and supplier are built as basic simulation elements. The construction of a supply chain can be realized through drag-and-drop and connection of those elements. For a particular supply chain, scenarios can be designed by changing the variables in the operational environment and disruptions readily evaluated. Some of the parameters of each variable are presented in the following table.

Variable	Operational Environment				Disruption	
	Inventory policy	Capacity	Forecast	Production Policy	Production Disruption	Delay
Parameter	sS, rS, sq	Different levels of capacity	Different levels of accuracy	MTO & MTS	Can occur in any facility	Can occur in any link

Challenge 4 – Can supply chain vulnerabilities be mitigated systematically for effective response to disruptions?

Problem description: With greater risks and vulnerabilities and increasing complexities in supply chains, how to provide responsive and effective "What if" analysis of the impact of disruptions and mitigation policies in complex supply chains becomes an issue of high attention from both practice and academia.

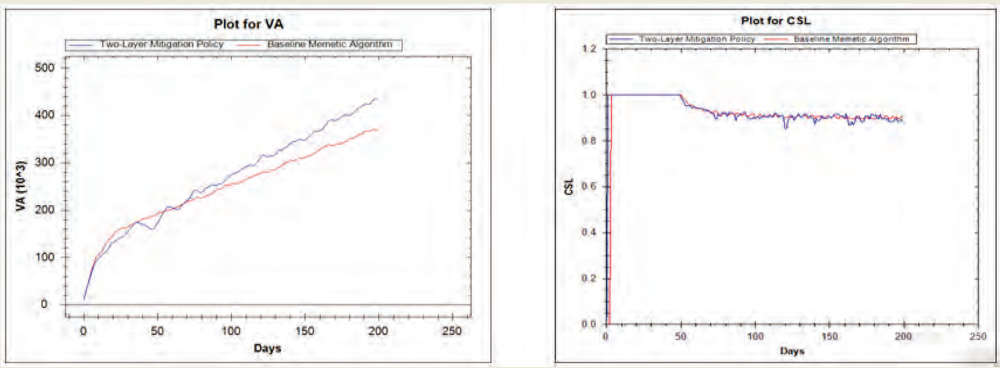
Solution approach: To overcome the limitations of the traditional approaches on providing responsive and effective "what if" analysis of a complex supply chain network, we developed an agent-based approach and models for investigating the performance behavior of supply chains. Enabling "what if" analysis of supply chain disruption and policies mitigates vulnerabilities. Agent-based simulation (ABS) technology is used to model companies, their interactions and risks behavior of supply chains.



An ABS model for studying SC disruptions and effectiveness of mitigation techniques

Results: The model takes demand, supply and supply chain structure data as inputs and produces results in key performance indicators (value-added, customer service level, total cost).

It can be observed from the results in the following figures that the Value-Added (VA) performance of the new mitigation policy (blue line) is generally better than the baseline Memetic algorithm over time. In terms of the Customer Service Level (CSL), the two-layer mitigation policy matches that of the baseline Memetic algorithm.



VA and CSL performance of the supply chain

Challenge 5 – Can resilience be assessed and quantified through a VaR approach?

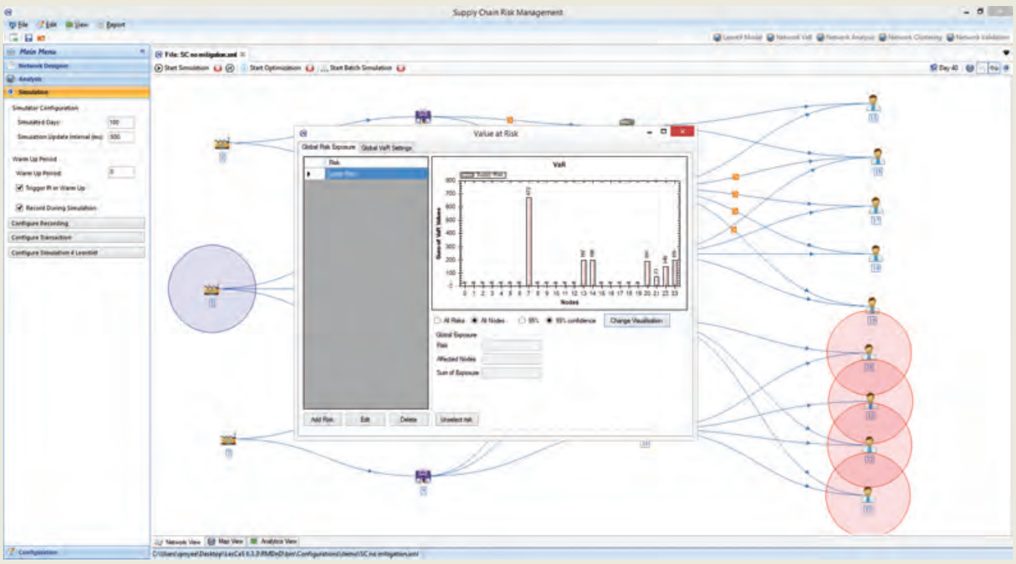
Problem description: Value at Risk (VaR) is commonly used for risk assessment by providing a quantitative analysis of risk. VaR is defined as a threshold value such that for a certain probability value, the amount of loss on the portfolio does not exceed this value within a specified time. For industry, the risk can be quantified using VaR based on "losses" which includes both tangible and intangible costs for a disruption.

Solution approach: We developed a new method for quantifying supply chain disruption risk using VaR based on time equivalence in terms of four recovery modes: abrupt, normal, fast, and slow. Based on these four recovery modal functions, we can define time equivalence (t_{eq}), to represent the recovery time based "loss" for the four different disruption recovery modes.

Results: This approach provides a new way for the supply chain company to conduct "what-if" analysis to measure the potential risks in the supply chain. For example, for a disruption, a "what-if" analysis can be conducted to quantify risk at a 95% and 99% confidence, respectively, for the four recovery modes.

		Confidence Level	
Recovery Mode	t_{eq}	**VaR (95%)**	**VaR (99%)**
Abrupt	14	$123,551	$116,737
Normal	7	$53,551	$46,737
Fast	3.518	$18,729	$11,914
Slow	10.482	$88,374	$81,559

Through the VaR tool, we will be able to see disruptions as indicated in red circles on the nodes in the supply chain. A pop-out window can be opened to look at the calculated VaRs. Depending on the level of confidence chosen, for every node at each time step, a bar chart is shown in the screenshot below.



III. RISK MITIGATION

With the risks now identified and prioritized, risk mitigation is the next step to making supply chains more robust and resilient through the adoption of preferred mitigation policies. Supply chain mitigation policies can be categorized into different types based on the risk issues including supply chain structure, visibility, resilience and buffer issues, etc. We have analyzed some typical issues and designed related mitigation policies in inventory control, sourcing strategy, resource pooling, and postponement.

Challenge 6 – Is there a novel inventory policy to mitigate supply chain vulnerabilities?

Problem description: Vulnerabilities manifest as supply lead time fluctuations or demand loss or uncertainty, play major roles in the increase of inventory cost. Inappropriate inventory policies, which do not take into account these risks and modify their parameters, may incur a huge cost in backorders or inventory levels at the onset of a disruption. An efficient and effective inventory ordering policy should consider these factors efficiently and effectively while determining policy parameters.

Solution approach: A new inventory policy, which adjusts its parameters according to the variation in demand, lead time or other cost parameters, is postulated. The policy – a 'time-adjusted' (r, Q) policy determines the r (reorder point) and Q (order quantity) values at the start of each defined time period based on the new demand forecast for order placement, rather than using the same r and Q values.

Results: In testing this policy with the existing inventory policy of a global MNC. The performance of the policies is proven to be more responsive and effective numerically under various demand distributions. The time-adjusted (r, Q) policy generally outperforms the manufacturer's existing policy under identified disruptions. The following figures show the impact on cost variations under lead-time variability and demand uncertainty, respectively, when demand is assumed to be *Normally* distributed.

Impact of lead time uncertainty on cost

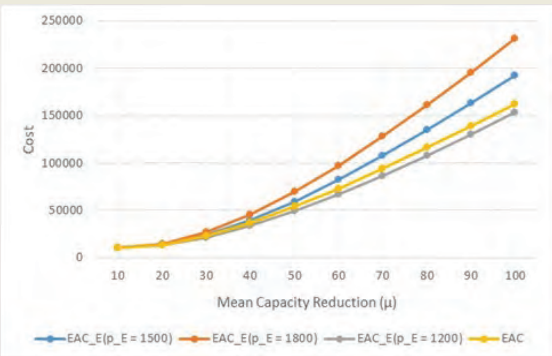
Impact of demand variability on cost

Challenge 7 – What emergency sourcing strategies work best under a supply disruption?

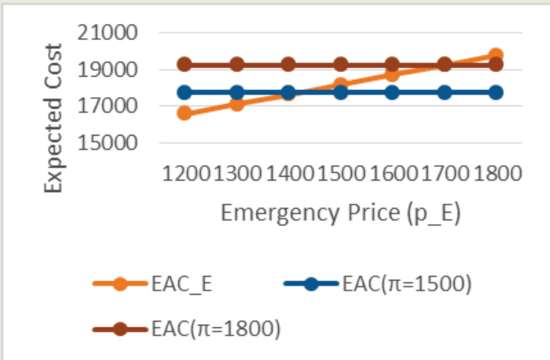
Problem description: A supplier's capacity is affected when a risk event occurs and it fails to deliver the requested products in time due to its reduced capacity. As a result, the manufacturer may face some penalties because of its failure to supply the products to customers in time. One way to mitigate the problem is to order some emergency replenishment from alternate suppliers or from the same supplier but from a different location, albeit at a higher price. But what price should the manufacturer pay for the emergency orders?

Solution approach: We consider only those risk events, which have low probability but high impact (LPHI). An exponential distribution is used to represent the reduction in supplier capacity. Based on this stochastic capacity, we develop an expression for the total inventory cost for the manufacturer when it places the order without considering capacity reduction. The cost includes lost sales because of its failure to supply customers due to the non-availability of parts. We also determine the inventory cost when emergency orders are placed to minimize the number of stock outs. Comparing the total inventory cost, we derive the necessary conditions for placing an emergency order.

Results: This study provides the necessary conditions under which the manufacturer should place an emergency order to minimize the total cost. The first figure shows how the expected average cost under emergency ordering (EAC_E) varies with mean capacity reduction (μ). It was found that EAC_E follows an exponential decay. The second figure presents both cost under emergency and cost without emergency ordering (EAC) for various prices for emergency ordering (p_E). A different penalty cost is considered for EAC. This graph can be useful in determining the p_E under which the manufacturer should place emergency orders.



Cost under emergency ordering vs mean capacity reduction



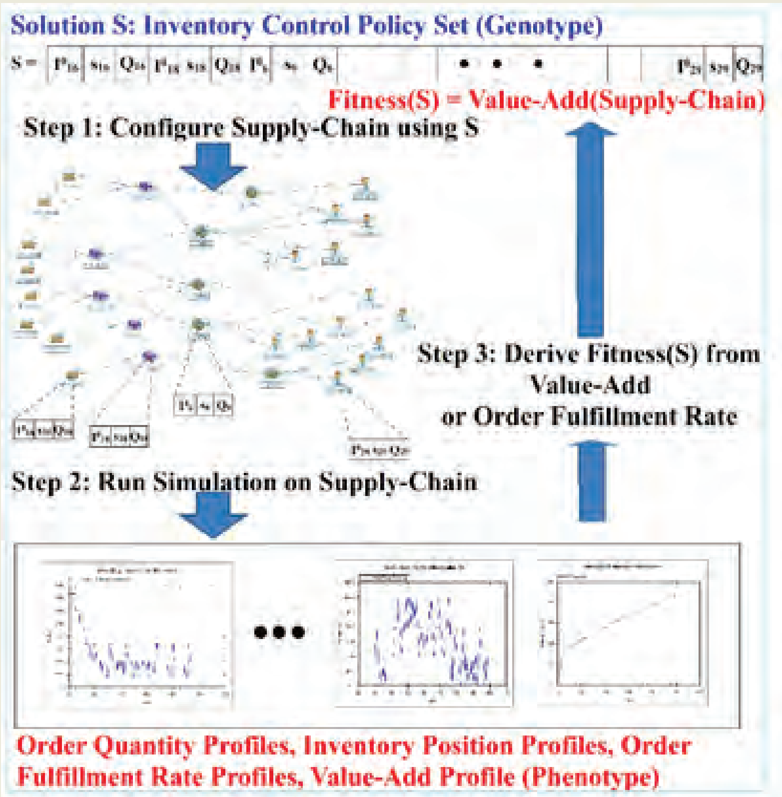
Cost with and without emergency ordering

Challenge 8 – Can the supply chain mitigate demand uncertainty through optimal allocation of safety stock?

Problem description: Demand uncertainty is one of the major vulnerabilities in supply chains. It is important to have a holistic approach that systematically allocates the optimal safety stock level for every node in the supply chain and, at the same time, coordinate the production plans of manufacturers and replenishment policies of distribution centers/retailers.

Solution approach: We use an evolutionary optimization and agent-based simulation at the upper layer to produce the series of inventory positions for all agents for a period of time, and use a look-ahead Model Prediction Control (MPC) algorithm to produce operational inventory positions based on actual demand information but with reference to the inventory positions.

The solution can meet the actual demand better and dampen demand fluctuation in the supply chain. The solution can also maintain good Value-Added performance at the same time with acceptable customer service level at the operational level. This approach is in a two-layer structure: an upper layer module for performance optimization and a lower-layer module for addressing demand uncertainty.



Results: The integrated inventory control algorithms designed are more effective and efficient than existing approaches in mitigating demand uncertainty in the supply chain, while allowing for various inventory related constraints to be evaluated.

IV. RISK MONITORING

After identifying the key risks, carefully choosing the right (networked) supply chain stakeholders, implementing mitigation strategies to improve robustness and resiliency, then a company still needs to monitor its operational processes for timely risk detection and early quick fixes. Thus, there is an immediate need for the visualization of impacts of these decisions, more so, when the supply chain is complex.

Challenge 9 – Can supply chain vulnerabilities be effectively visualized for responsive decision-making?

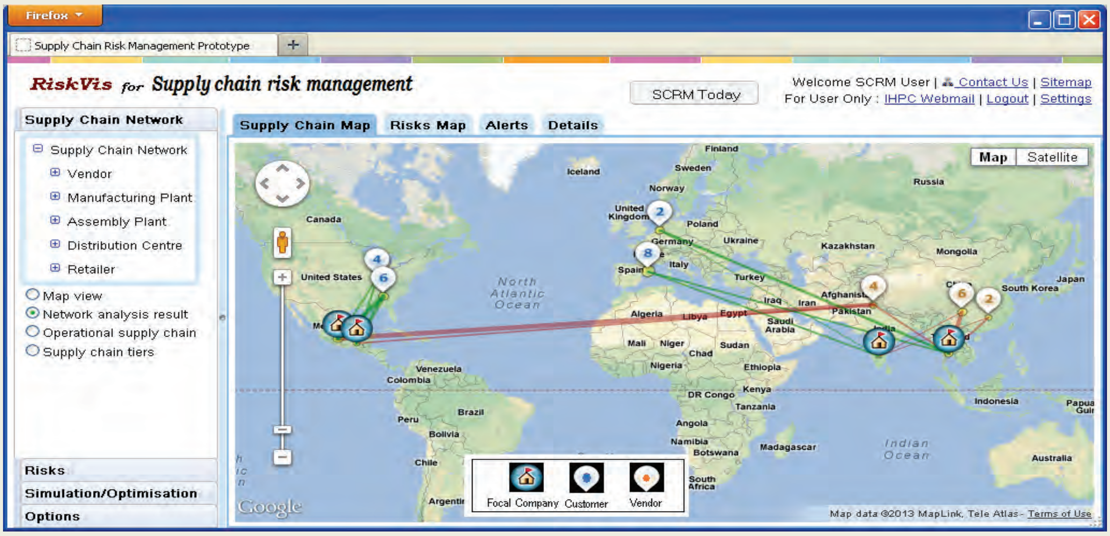
Problem description: Supply chain visualization tools for risk tracking and analyzing are important for companies as the cost of being unprepared and the lack of visibility for potential and ongoing disruptions could be immense.

Solution approach: The supply chain networks and their key entities can be mapped and visualized based on their physical locations. The visualization platform has implemented the following functions:

- A visualization dashboard
- Tracking of disruption events associated with the geographical locations of the supply chain nodes
- Display of temporal, spatial and connectivity patterns
- Scenario analysis to prepare the plan for supply chain risk mitigation

Results: The supply chain visualization platform (RiskVis) enables the timely capture of data from the other modules addressing the respective challenges including risk identification and mitigation and network-based analysis, modeling and simulation. These collect, monitor and analyze critical items such as:

- Inbound and outbound logistics: it can help to detect shipment delays and understand the movement of material/parts/products along the supply chain.
- Inventory level: It can keep obsolescent inventory at minimal levels while providing enough buffer for unforeseen events.
- Order fulfillment and manufacturing operations.
- Risks such as natural disasters that might affect part of the supply chain.



V. MASTER FACILITATIVE CONTROL TOWER

Generally, a control tower is designed to facilitate material or information flows among partners in one supply chain. It can also provide information and enable collaboration among supply chain members in times of risk. However, as today's supply chain networks become complex and one node may play a part simultaneously in several supply chains, thus the concept of the master facilitative control tower (MFCT) is developed to design and develop risk tracking methodologies crossing different intersecting supply chain networks (Figure 7).

Figure 7. Concept of master facilitative control tower

Some main features of the MFCT are as follows.

- Provide a management platform for risk information sharing and infusion.
- Facilitate collaboration in producing integrated and quick fix highly responsive solutions.
- Provide analysis and insights about cascading risk propagation across integrated supply chain networks
- Provide a visualization about connectedness in supply chains and the identification of key linkages in and across the networks
- Provide for an integrated response based on the challenges inherent in risk identification, assessment and mitigation, and monitoring.

Challenge 10 – Is a Master Facilitative Control Tower (MFCT) for supply chain risk management feasible?

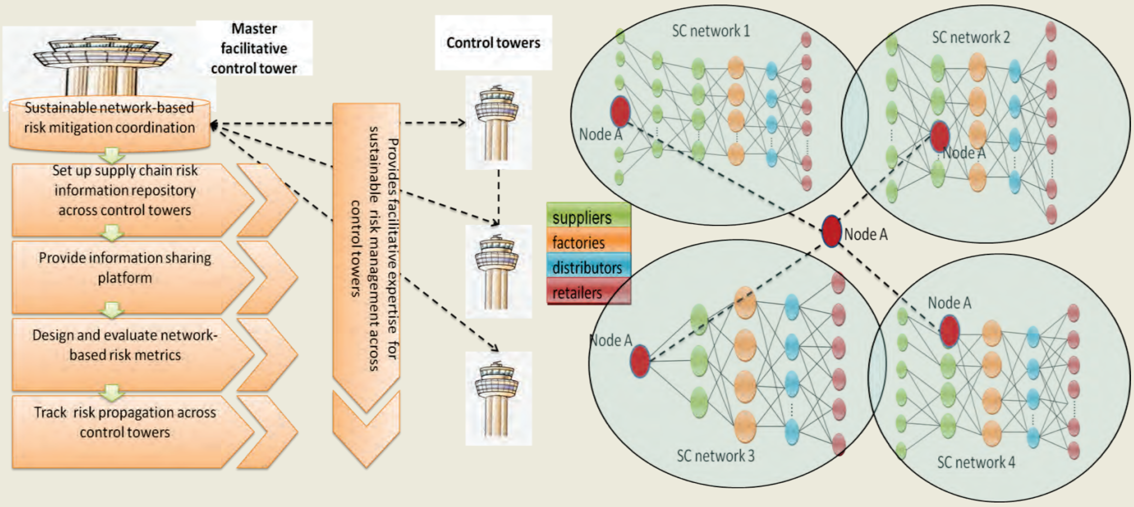
Problem description: There is, we believe a consensus to manage supply chain disruption risks in an optimal way considering the sustainability of supply chains for long-term development with the synergy of environmental protection and disaster recovery. Therefore a neutral coordination mechanism, the MFCT, is important to provide facilitative functions for assisting the understanding of risk propagation and coordination of network-based risk management in a sustainable way across networks.

Solution approach: The developed MFCT framework, integrating data modelling, analytics and simulation on top of the visualization platform, is able to provide win-win solutions for the coordination of control towers for facilitating the efforts of sustainable supply chain risk management. The facilitative functions of the MFCT are as follows:

- Provide insights for assisting response to supply chain disruptions.
- Provide insights on cascading risk propagation across integrated supply chain networks.
- Provide a complete picture in respect to connectedness in supply chains
- Provide inbound and outbound warnings about risk propagation
- Provide identification of key linkages in the networks

Results: Information from individual control towers are categorized and protected with different levels of authorized access. With coordination and information sharing across control towers, risks can be evaluated proactively with risk mitigation compliance considering the temporal, spatial, and topological impact of integrated supply chain networks in supply chain evolution and during disruptions.

MFCT plays a neutral role in the business environment. It only takes the aggregated information, i.e., the estimated overall bi-directional transaction percentages, from each individual supply chain network. From the view of the MFCT, the possible impact of Node A to the entire integrated network can be measured, although this is beyond the scope of one particular control tower.



The MFCT framework

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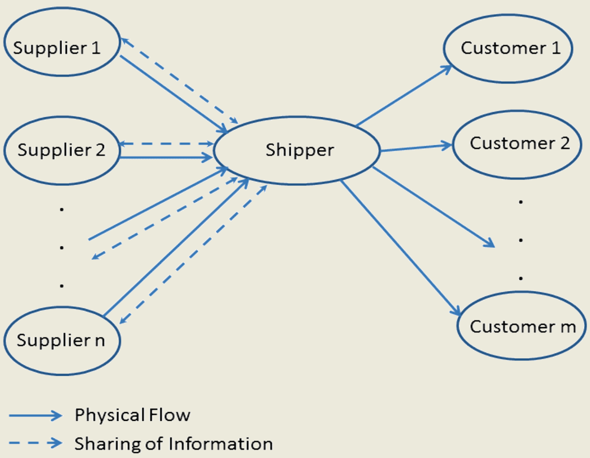
Challenge 11 – Can information sharing in supply chains be incentivized?

Problem description: As one of the pillars in supply chain coordination, information sharing among supply chain players (nodes) plays a significant role that can help to mitigate supply chain disruptions effectively. The key challenge is on how to incentivize different players in the supply chain to share information. Voluntary information sharing may not always be sustainable as it is not requisite that every player will benefit. So given a degree of information to be shared among nods in the supply chain where each player is an independent profit-maximizing node, an incentive scheme is needed which will help to create an information-sharing agreement among the players. This incentive scheme must meet the minimum requirement that every player will not be worse off compared to the situation when they do not participate in information sharing.

Solution approach: A game theoretic approach is adopted to develop an incentivizing mechanism which may be in the form of contracts among different players within a supply chain. The general approach is summarized as follows:

- Identify risk mitigation strategies based on the degree of information sharing between players
- Develop a system dynamics model to quantify the benefit of information sharing based on the mitigation strategies
- Use a game theory approach to identify incentive mechanism(s) which will encourage players to participate

Results: Preliminary result shows that when different suppliers have high levels of uncertainty in their capacities both before and after a disruption, voluntary vertical information sharing is not possible due to the additional cost of information sharing incurred by the suppliers. Hence this is an example of the classical *prisoner's dilemma* and a mitigation strategy is recommended in order to improve the overall supply chain efficiency while maximizing the individual player's payoffs. When a mitigation strategy is found, this means that a Nash equilibrium is reached and this can be obtained by observing the payoff matrix. By comparing the outcomes of the Nash equilibrium strategy with those under other strategies, good risk mitigation strategies are to be identified in order to achieve an overall efficiency of the whole supply chain.



CONCLUSION

In this white paper, we have presented eleven challenges in the robustness and resiliency of networked supply chains. These challenges have arisen from a grand set of many challenges that have, in turn, been categorized in each of the four phases of supply chain risk management (see Figure 5). In order to feed those solutions with timely and accurate information to pinpoint the source of risk, assess the impact, and identify the right mitigation strategies, the concept of a master facilitative control tower is posited as the grand challenge.

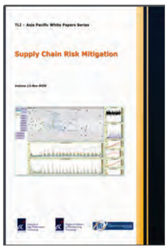
Completing the work in Phase 1 will result in a data-integrated modular solution with a uniform graphical user interface. Work is ongoing. In Phase 2, we especially invite collaboration from companies, singly or in a consortium to test-bed these solutions. Companies can also take advantage of the current solutions to improve their capability in supply chain risk management.

Publications under Master Facilitative Control Tower for Risk Management of Complex Supply Chains and Ref Number: 1121790043 and 1124204049*).*

Whitepapers:

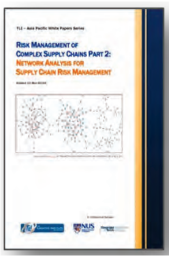
Master Facilitative Control Tower for Risk Management of Complex Supply Chains – An Overview *(Vol 13-Nov-RISK)*

Master Facilitative Control Tower and Visualization Framework *(Vol 13-Nov-RISK)*

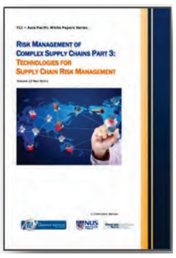


Supply Chain Risk Mitigation *(Vol 13-Nov-RISK)*

Risk Management of Complex Supply Chains Part 1: Supply Chain Risk and Complex Systems *(Vol 12-Nov-SCI09)*



Risk Management of Complex Supply Chains Part 2: Network Analysis for Supply Chain Risk Management *(Vol 12-Nov-SCI10)*



Risk Management of Complex Supply Chains Part 3: Technologies for Supply Chain Risk Management *(Vol 12-Nov-SCI11)*

Journal Papers:

1. Qu, S.J., Goh, M., de Souza, R., Proximal Point Algorithms for Convex Multi-criteria Optimization with Applications to Supply Chain Risk Management, Journal of Optimization Theory and Applications.
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