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RISK MANAGEMENT OF COMPLEX SUPPLY CHAINS PART 2: NETWORK ANALYSIS FOR SUPPLY CHAIN RISK MANAGEMENT

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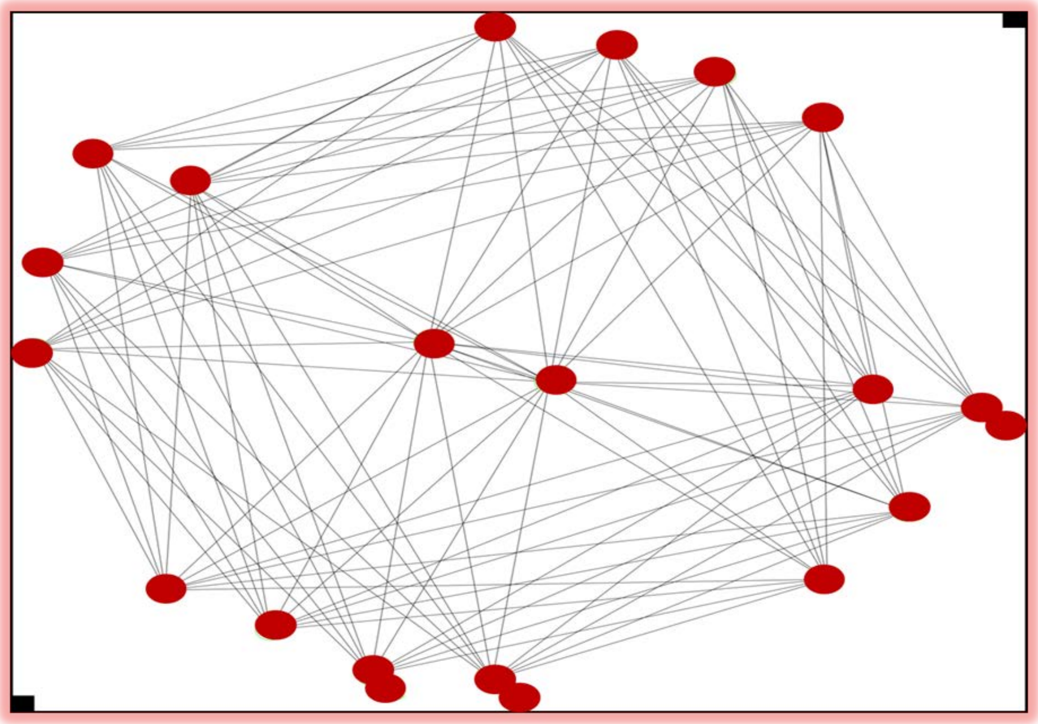

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Institute of High Performance Computing

A Collaboration Between

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The Logistics Institute Asia Pacific

RISK MANAGEMENT OF COMPLEX SUPPLY CHAINS PART 2:

NETWORK ANALYSIS FOR SUPPLY CHAIN MANAGEMENT

NEAT management using Net-A

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EXECUTIVE SUMMARY

Supply chains in the current age are complex networks as the result of globalization, outsourcing, and lean initiatives. Globalization increases the complexity of the traditional supply chain yielding more nodes, longer links, greater connection among the links, and more collaboration among the nodes. Outsourcing provides the benefit of economies of scale but at the same time weakens the direct relationship between buyers and suppliers or shippers and carriers. Lean initiatives such as just-in-time practice promote supply chain efficiency as they get rid of inventory buffers, which are critical to help a supply chain to sustain and recover when facing disruption risks.

In this complex environment, we hypothesize that the efforts from a single company in the context of a network is far from enough to cover it from many risks, especially those passed down from other companies, or those from risk reactions of a competitor company. The traditional mitigation approaches are limited in those areas. Risk management of complex supply chain networks is thus important and urgently needed, especially when the past decade has witnessed an ever-increasing number of disasters and disruptions to business.

A framework of supply chain risks should be developed to cover all possible types of risks to help companies systematically identify the potential risks. Under an environment of imbedded risks, the network of supply chains should be studied to understand the propagation of such risks. Finally, the technologies to manage supply chain risks should be reviewed in order to determine the state of progress. The three topics are addressed in a series of three white papers conducted by a research consortium of TLIAP, IHPC and SIMTech, which is supported by A*Star to study the implication of risks for a complex supply chain network.

This white paper is part two of the series that presents an outline on risk tool for supply networks, reviews the advantages of using a network perspective, and introduces a network analysis framework for Supply Chain Risk Management. Visuals of a simple prototype of supply chain visualization are presented towards the end of the white paper.

1. INTRODUCTION

Supply chains of modern era are dynamic, complex and highly interdependent in nature. The competitive nature of these complex supply chains put them at considerable risk and hence, supply-chain-managers need to evaluate and manage risks from various sources and settings. Supply chains of the past had the luxury of firms manufacturing in-house, goods sourced locally and products sold directly to the customers. Hence, the associated risk was less dispersed and relatively easy to manage. However, with the introduction of increased product/service/process complexity and outsourcing of supply networks across international borders, risk associated with supply chain management is growing and has the potential to disrupt the whole supply network if ill-managed (Harland, 2003).

A supply chain can be considered as a complex system aka “supply network”, consisting of a set of entities/actors, activities, technological/physical infrastructures and policies involved with the procurement of raw materials, conversion of these raw materials to finished product, and logistics for the manufacturing-to-delivery of these products. A typical “supply network” comprises ties to its immediate suppliers and customers, and ties between them and their immediate suppliers and customers. Supply chains are continuously evolving and adapting systems, which are primarily driven by complex sociotechnical inter-firm interactions. Traditional modeling approaches for supply chain risk management have primarily focused on technical issues and are insufficiently equipped to effectively capture their complex structural/behavioral aspects. Network analysis based approaches offers attractive alternatives to overcome these theoretical and methodological gaps.

Recently, there is an emerging trend in embracing network analytic based approaches to understand, design, and manage supply chains (Kim et al, 2011). Network analysis uses theories from the social, organizational, and complexity sciences theoretic methods to understand, model, analyze, and visualize the structure, dynamics, and strategies that shape supply chain risk management (Bellamy et al, 2012). Network analysis has lately gained reception among supply chain researchers for its ability to integrate the operations and supply risk management with its counterparts of management science. This is evident from the surge in network analysis related publications in supply chain systems in the recent years (126 in total), as shown in Figure 1.

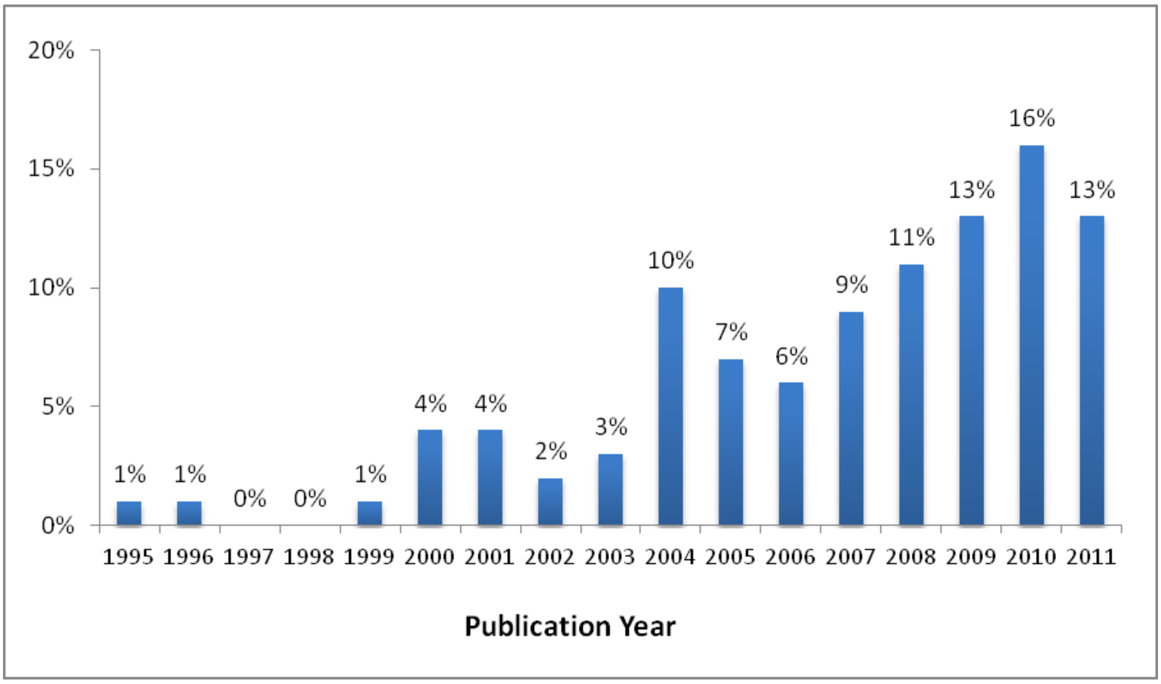


Figure 1. Percentage distributions of the number of publications by year[1]

This white paper presents an overview on risk tool for supply networks, summarizes the advantages of using a network perspective, and introduces the reader to social network analysis and a network analysis framework for Supply Chain Risk Management. Visuals of a simple prototype of supply chain visualization are presented towards the end of the white paper.

[1] Figure reproduced from "Bellamy, M.A. and Basole, R.C (2012). "Network Analysis of Supply Chain Systems: A Systematic Review and Future Research," forthcoming, *Systems Engineering,* Vol. 16, Issue 2, pp. 1-20

2. SUPPLY CHAIN RISK MANAGEMENT[2]

2.1. Risk

Risk, in general, can be defined as a chance of damage, loss, injury or any other undesired consequences. Royal Society defines risk as 'the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge'. Harland et al. define risk (R) as the product of the probability (P) of a loss (loss) and the significance or impact (I) of the loss, related to an event n (n): $R_n = P(loss)_n \times I(loss)_n$.

2.2. Types of risk

Harland et. al classify risk into the following 11 types based on their impact:

No.	Type	Impact
1	Strategic risk	Affects business strategy implementation
2	Operations risk	Affects a firm's internal ability to produce and supply goods/services
3	Supply risk	Adversely affects inward flow of any type of resource
4	Customer risk	Affects likelihood of customers placing orders
5	Asset impairment risk	Reduces utilization of an asset and can arise when the ability of the asset to generate income is reduced
6	Competitive risk	Affects a firm's ability to differentiate its products/services from its competitors
7	Reputation risk	Erodes value of whole business due to loss of confidence
8	Financial risk	Exposes a firm to potential loss through changes in financial markets
9	Fiscal risk	Arises through changes in taxation
10	Regulatory risk	Exposes the firm to changes in regulations
11	Legal risk	Exposes the firm to litigation with action arising from customers, suppliers, shareholders or employees

[2] This section is based on "Harland, C. (2003). Risk in supply networks *Journal of Purchasing and Supply Management, 9* (2), 51-62".

2.3. Risk Tool for Supply Networks

Complexity of the supply chains has increased the need for evaluating and understanding risk in supply chain management. The assessment process typically asks two questions (Harland et al., 2003):

- How likely is it that an event will occur?
- What is the significance or consequence if the risk occurs?

The tool for managing risks in supply chain networks proposed by Harland et al., is shown in Figure 2. Mapping the supply network is likely to involve understanding who owns what, and what are the key measures currently in place, i.e. clarity of role and responsibility within the network (Harland, 2003).

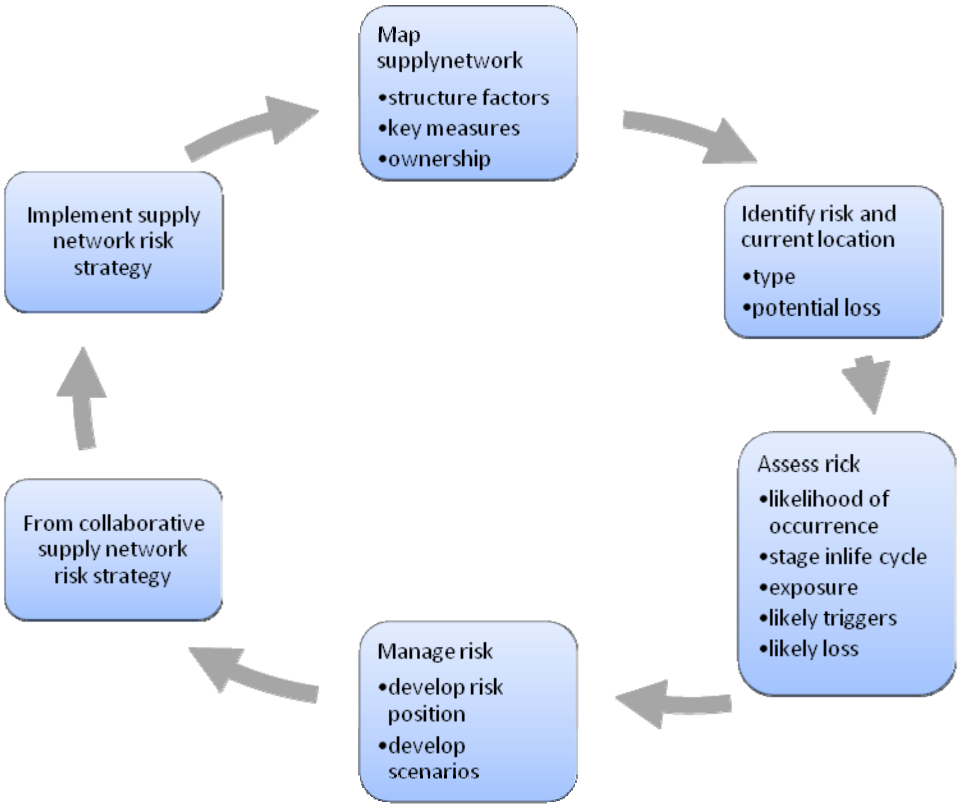


Figure 2: Tool for managing risks in supply networks[3]

[3] Figure reproduced from "Harland, C. (2003). Risk in supply networks *Journal of Purchasing and Supply Management, 9* (2), 51-62".

3. NETWORK ANALYSIS FOR SUPPLY CHAIN RISK MANAGEMENT[4]

3.1. Supply Chain versus Supply Network

The conceptualization of a supply chain as a chain has resulted in them being labeled from a focal firm perspective, ignoring the interdependencies between the entities of the supply chain. The interdependent nature of supply chains can be more accurately explained by a network. The key difference between the perceptions of a chain over a network is as follows:

- A supply chain describes the flow of information, materials and cash into/out of a focal company; and
- A supply network describes the connections between supply chains that share common elements.

3.2. The Supply Chain Network

No business firm can, on its own, produce its products from raw material to a finished product. Every company is dependent on a network of relationships to other companies where material and/or services are merchandized. Universally, one puts the attention on a focal company that is reliant on a number of suppliers for the input to its product. A simplified design of the linkages and actors in a supply chain network is illustrated in Figure 3. On the supply side, the focal company is linked to tier 1, tier 2 to tier 3 suppliers. In Figure 3, it can be noted that tier 1 suppliers are those that have a direct link with the focal company while tier 2 suppliers have links to tier 1 supplier. Hence, Tier 2 suppliers are subcontractors to the focal company. Lambert and Cooper (2000) present three dimensions to describe the structure of a supply network:

- Horizontal structure
- Vertical structure
- Horizontal position of the focal company

[4] This section is based on "Phil Greening, & Christine Rutherford (2011). Disruptions and supply networks: a multi-level, multi-theoretical relational perspective *International Journal of Logistics Management, 22* (1), 104-126" & "Nojan Najafi et al. Supply Base Structuring: Introducing the Supply Network Model"

The horizontal structure refers to the number of tiers across the supply chain. The vertical structure refers to the number of suppliers represented within each tier. The horizontal position of the focal company denotes where in the supply network the focal company is positioned.

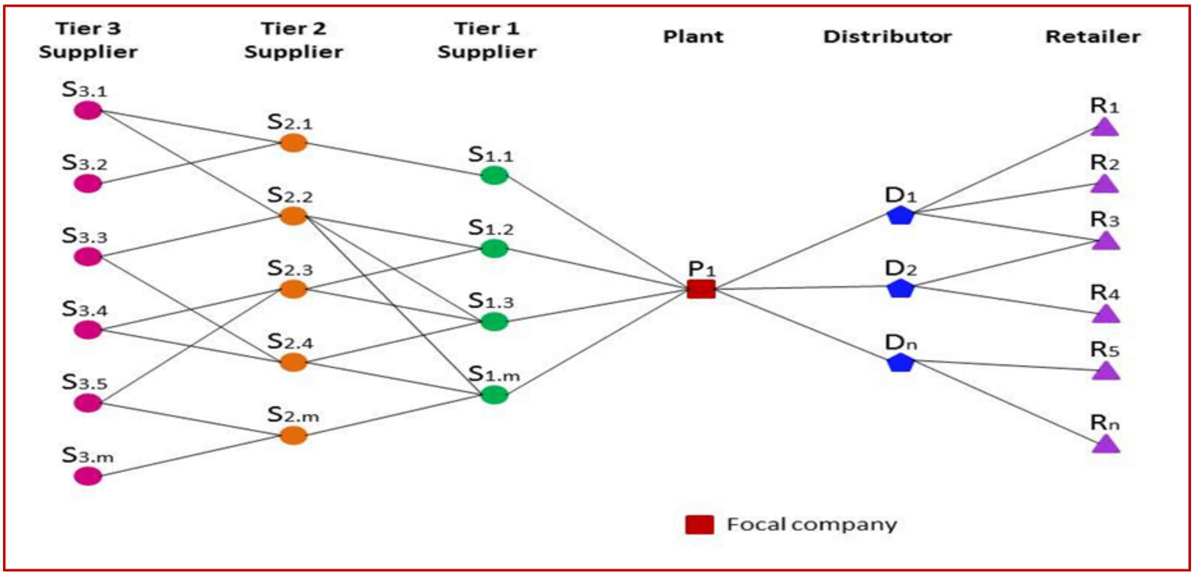


Figure 3: A typical Supply Chain Network[5]

3.3. Advantages of using a Network Perspective (Brookes and Lewis, 2006)

- Network models allow actors to interact in a diverse way. Also, they allow the model to differentiate between actor categories, which allow the model to simultaneously capture different supply chains and the interactions between them.

- Network models allow for an array of bi-directional relational ties, which allow the model to capture the type of complex reverse flows associated with 'whole life cycle effects' on supply chains.

- Network models allow relational ties to carry a wide range of information, which could be used to capture more behavioral aspects – such as levels of trust or perceived risk in a transaction.

[5] The authors thank 'Zhou Rong & her team @ TLIAP' for the original version of the figure.

3.4. Social Network Analysis

Social network analysis (SNA) is a branch of sociology that studies collections of individuals and the associations among them. A social network can be defined as a network that consists of a finite set(s) of actors and the relation(s) defined on them. A social network model comprises the following five components (Mueller, 2007):

- A set ***N*** of actors
  - The actors ***N*** in a network can be anything that can be represented by nodes in a graph. In a supply network, the actors could be the producers, processors, transporters, retailers, regulatory agencies, or certification providers.
- A collection ***L*** of links or ties that represent relationships between ordered pairs of actors
  - In a supply network, this could be flows of material, flows of money, flows of product information, information required to carry out transactions, or of meta-information required for network coordination.
- A *"socio-graph"* G_d consisting of nodes that represent actors, and directed or undirected lines between the nodes, which represent the relations among actors
  - Encoded by the size, color, or shading of the dots. Directed links are represented by arrows and valued links are represented by lines with numbers attached.
- A socio-matrix or adjacency matrix **A** that has as many rows and columns as there are actors and where the elements $x_{i,j}$ record the relationships between actors i and j; and
  - The adjacency matrix **A** of a network is a quadratic matrix which has as many rows and columns as there are actors in the network and the elements a_{ij} of this matrix represent the links or ties between the actors.
- A characteristics-matrix **C**, which has as many rows as there are actors and as many columns as there are attributes of interest. A social network then is defined by: $S = \{ N, L\ G_d, \mathbf{A}, \mathbf{C} \}$
  - Social network analysis is concerned with the relationships among actors and actor attributes other than those related to the network are a secondary concern. Data on these characteristics may then be assembled in an actor characteristics matrix ***C*** which has as many rows as there are actors in the network and a column for each actor characteristic.

3.5. Literature Review

Bellamy and Basole (2012) conducted a systematic review of network analysis publications in supply chain systems using the following keywords: “network theory”, “network analysis”, “complex network”, “complex adaptive system”, “social network analysis”, “supply network”, "network structure”, "network evolution”, “network emergence”, “network dynamics”, and “network strategy”, “operations management”, “supply chain”, “supply chain management”, and “extended enterprise". After a detailed systematic screening, they selected 126 articles and classified the focus area into three themes, as shown in the following table:

	Theoretical Motivation	Related Disciplines	C	E	M/S	R
SCS Structure	Social Network Theory; Complexity Theory; Systems Theory	Organizational Theory and Behavior; Strategic Management; Sociology	18	31	5	5
SCS Dynamics	Complexity Theory; Evolutionary Economic Theory; System Theory	Evolutionary Biology; Ecology; Computational Physics; Systems Engineering	10	8	4	3
SCS Strategy	Institutional Theory; Resource-Based View; Resource Dependence Theory; Social Capital Theory; Social Exchange Theory	Economics, Organizational Theory and Behavior; Strategic Management; Sociology; Marketing	61	66	9	13

Conceptual (C), Empirical (E), Modeling/Simulation (M/S), Review (R)

3.6. The Supply Network Model

The Supply Network Model formation consists of five steps; map, evaluate, match, develop and improve, as shown in Figure 4. The first step of the model formation is to map the resource ties, actor bonds and activity links in the network. This mapping will be fed to the next step, where the network is evaluated based on the horizontal/vertical integration of supplier relationships, using the Supply Network Matrix Model. Depending on the level of integration, various supply base strategies results. Once the evaluation is done, then a match should be made to identify the mismatch between the firm’s expectations and what it has. After this match/mismatch identification step, the next step is to develop the links that are required to form the new network. Finally, this process should be done on a cyclic basis to constantly improve the supply base network.

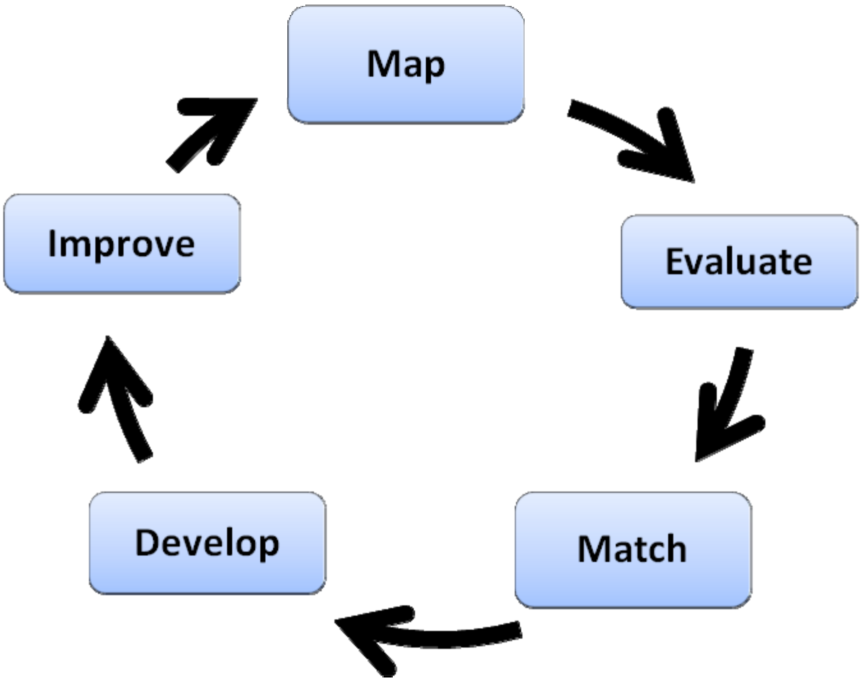


Figure 4. The Supply Network Model[6]

When a company has mapped its supply network, it should evaluate the network so as to specify the characteristics of the network. The interrelationships in a network are evaluated by measuring two different parameters.

- The first one is the *level of horizontal integration.* This metric is used to evaluate the information sharing in the supply chain, mainly related to activities, e.g. sales data, manufacturing schedules etc.,

- The second dimension corresponds to the *level of vertical integration*, which concerns how the suppliers in a certain tier relate with each other.

Based on the level of integration, the supply network can be categorized into four different categories, as illustrated in Figure 5. Illustrations for each type are shown in Figure 6.

[6] Figure reproduced from "Nojan Najafi et al. Supply Base Structuring: Introducing the Supply Network Model"

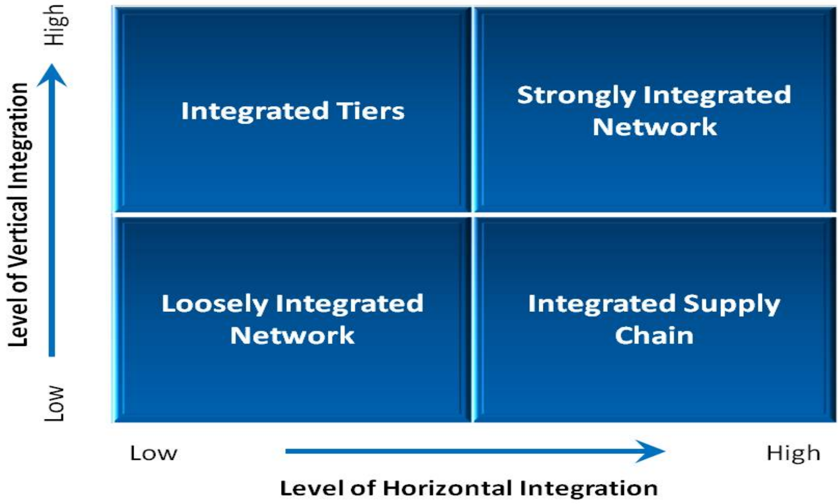


Figure 5. The Supply Network Matrix Model[7]

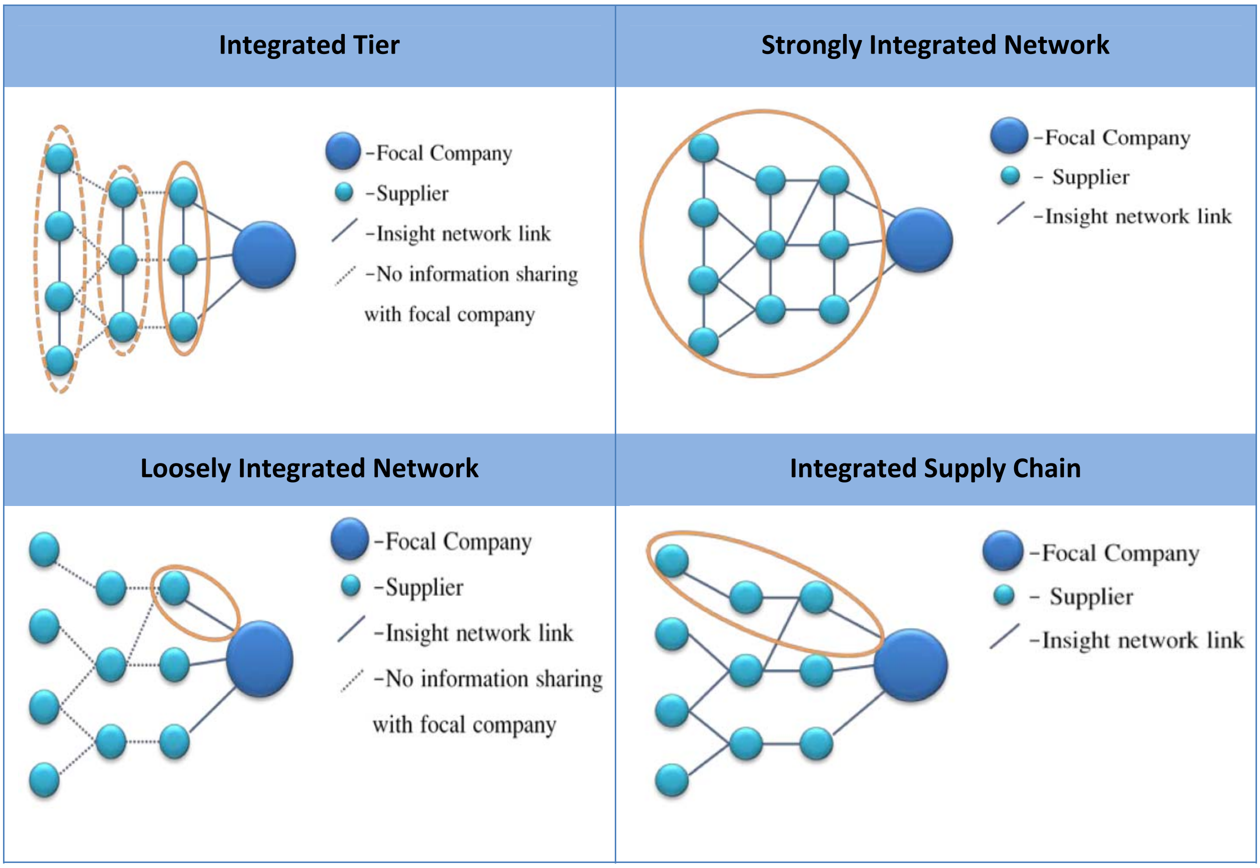


Figure 6. Illustrations for the supply network matrix model[8]

[7] Figure reproduced from "Nojan Najafi et al. Supply Base Structuring: Introducing the Supply Network Model"

[8] Figure compiled from illustrations published in "Nojan Najafi et al. Supply Base Structuring: Introducing the Supply Network Model"

4. NETWORK ANALYSIS FRAMEWORK FOR SUPPLY CHAIN RISK MANAGEMENT[9]

4.1. Structural attributes of a Supply Network

The interaction between entities of the network gives the network a set of characteristics that can be used to predict its behavior as it evolves. Entities that enjoy controlling access over other entities or resources of a network are assumed to hold positions of inbetweenness centrality. These entities exert power over the network. Such entities can afford not to negotiate norms but determining them – just as nodes with high-degree centrality (more connections than other nodes) enjoy advantaged access to other network entities. Density echoes the concentration of ties within a network, holes reveal the lack of connection between clusters, weak ties the relative strength of relationships, and equivalence mirrors the similarity of organizations structural position. Figure 7 provides an illustration of the network structural attributes.

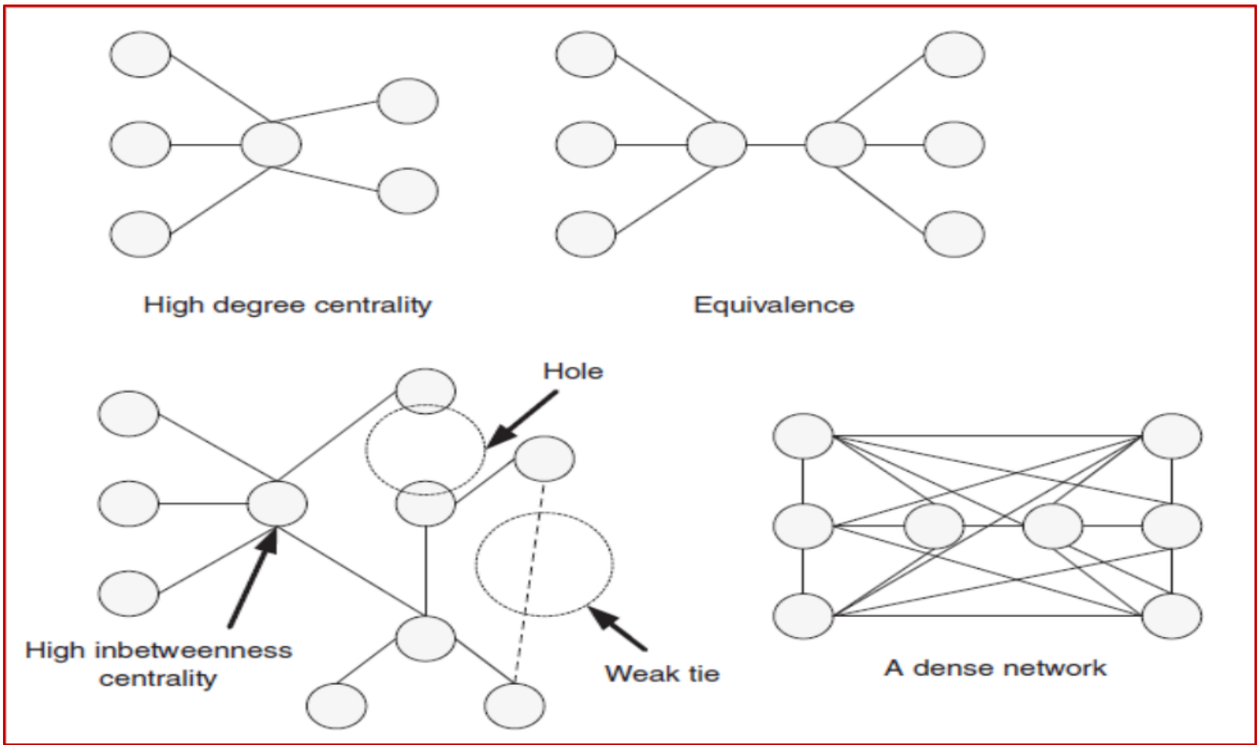


Figure 7. Network structural attributes[10]

[9] This section is based on "Phil Greening, & Christine Rutherford (2011). Disruptions and supply networks: a multi-level, multi-theoretical relational perspective *International Journal of Logistics Management, 22* (1), 104-126"

[10] Figure reproduced from "Phil Greening, & Christine Rutherford (2011). Disruptions and supply networks: a multi-level, multi-theoretical relational perspective *International Journal of Logistics Management, 22* (1), 104-126"

4.2. Disruptions in a Network

Disruptions, a type of risk, comprise the deletion of ties/nodes from the network – permanently or temporarily – as a consequence of some unexpected event. Hence, the post-disruption network structure is irreversibly dissimilar to the pre-disruption network. The subsequent adaptation process, predictably, involves the remaining actors renegotiating existing and in some cases establishing new relationships, resulting in a permanent change to the network structure.

Greening and Rutherford (2011) hypothesize that each of the network attributes has a specific implication in the way the networks respond to disruption. For example, a disruption happening at a node with high inbetweenness centrality will end in a greater disconnection amongst the network actors than a disruption occurring in a node with low inbetweenness centrality. Similarly, holes represent opportunities for nodes to build new connections with previously unconnected nodes following a disruptive event. Nodes with high-degree centrality enjoy a privileged position of power, which they may or may not use to their advantage, and this is in contrast with the network attribute of equivalence, which describes nodes, with no comparative privilege.

4.3. Conceptual framework

The structure of a supply network plays a vital role in both the evolution of the network and its response to disruption. The network structure's influence in determining the severity of a disruption, and the time taken by the network to recover are key components to be addressed in risk management surrounding disruptive events. The network perspective presumes that roles are reflected in network structure; for instance, high-degree centrality supposes power, which in turn presumes the potential to coordinate. To this end, Greening and Rutherford (2011) summarize as to how a network will respond to disruption, and the time it takes for the network to recover through a conceptual framework (see Figure 8). They also propose a series of propositions defining a future research agenda.

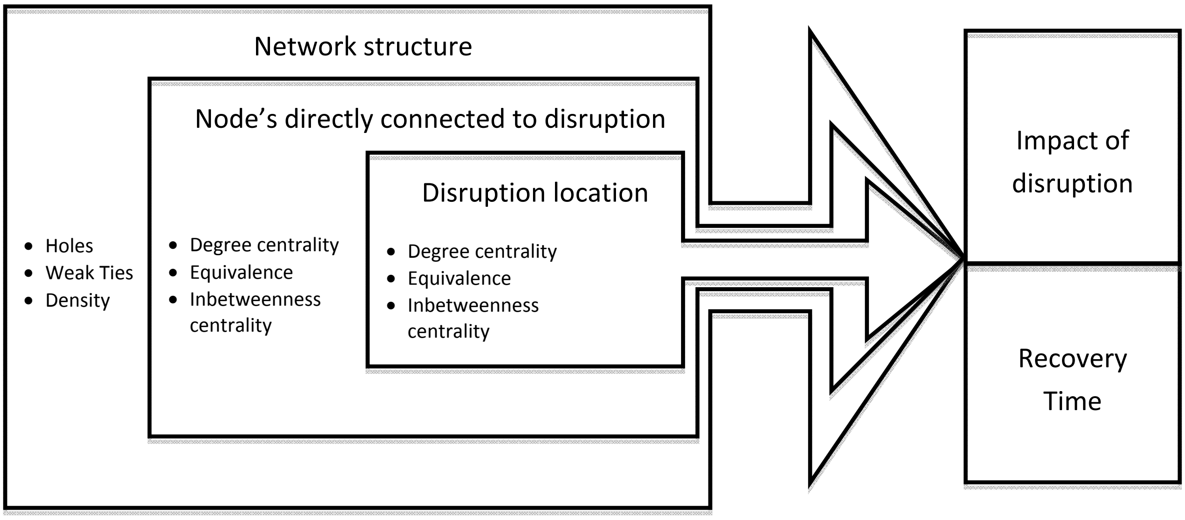


Figure 8. Conceptual framework proposed by Greening and Rutherford (2011)[11]

4.4. Research propositions

The conceptual framework proposed by Greening and Rutherford (2011) directs the development of research propositions[12] towards structuralist explanations of network behavior:

1. The time taken for a network to recover will be greater in dense networks, compared to the time taken for less dense networks to recover.
2. The impact of a disruption will be greater in less dense networks than in more dense networks.
3. Disruptions in dense networks will result in greater instability across the network during the recovery phase.
4. Networks with a higher proportion of holes, and associated high dependency ties, will experience greater disruptive impact on those networks with fewer holes.
5. Networks with a high proportion of holes, and associated high dependency ties, will take longer to recover from a disruptive impact than those networks with fewer holes.
6. Disruptions in structurally evolving networks will have greater impact than in mature networks with proportionately less holes.

[11] Figure reproduced from "Phil Greening, & Christine Rutherford (2011). Disruptions and supply networks: a multi-level, multi-theoretical relational perspective *International Journal of Logistics Management, 22* (1), 104-126"

[12] Propositions reproduced from "Phil Greening, & Christine Rutherford (2011). Disruptions and supply networks: a multi-level, multi-theoretical relational perspective *International Journal of Logistics Management, 22* (1), 104-126"

7. Nodes whose shortest connecting path to a disruptive event is via a weak tie will be impacted less than a node whose shortest connecting path is through a greater number of strong ties.
8. Nodes whose shortest connecting path to a disruptive event is via a weak tie will recover more quickly than a node whose shortest connecting path is through a greater number of strong ties.
9. The co-location of influence (as a result of degree or inbetweenness centrality) and disruption will result in greater impact than the location of disruption at nodes of lesser influence.
10. The co-location of disruption and power will result in longer network recovery periods than the dislocation of disruption and power.
11. Disruptions connected to powerful nodes (described by centrality) will result in less impact and then accelerated recovery period when compared to disruptions connected to less powerful nodes.

5. VISUALIZATION

The growing demand for mass customization in many industries has resulted in the complexity of today's supply chains and the high level of uncertainty and risks that companies are facing. As supply chain networks (SCNs) are more-interconnected, non-linear, inter-dependent, global, complex and stochastic in nature, these "risky" characteristics of the SCNs present even greater challenges in strategizing risk-mitigation measures during abnormal events. With increased complexity, SCNs face high risks and inefficiencies due to limited visibility. While managers know about the impact of delays, inaccurate data or shrinkage, they rarely know why and cannot see where the problems in the supply chain originate from. Thus, there is an immediate need to provide end-to-end supply chain visualization for efficient control and management of complex supply chains. This section presents a few snapshots of a simple prototype of supply chain visualization that we have developed.

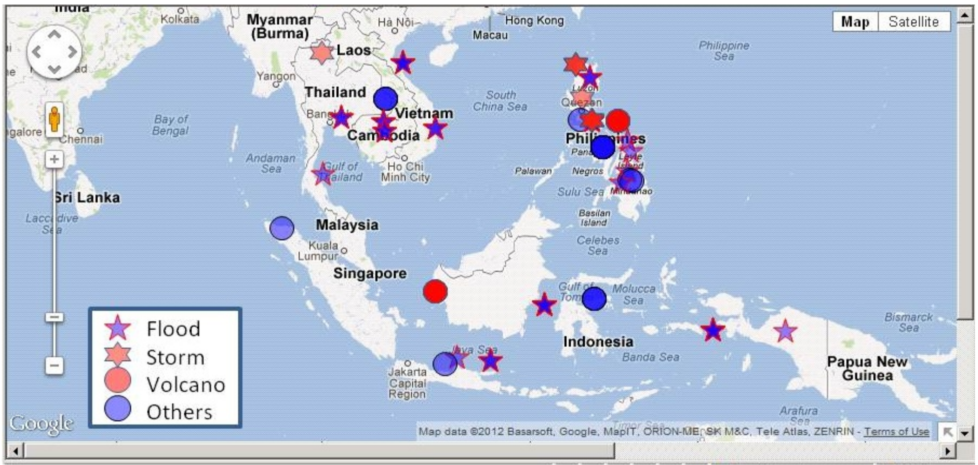
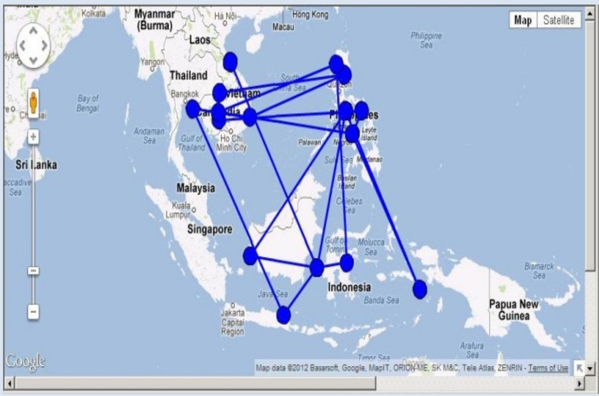
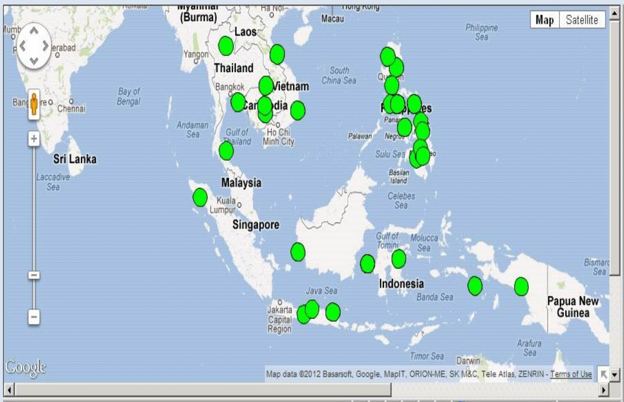
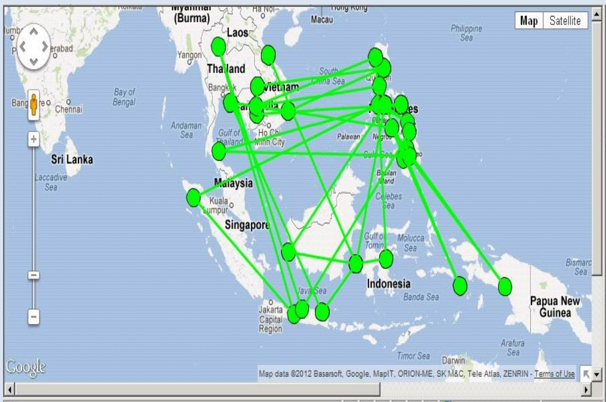


Figure 8. Visualization of disasters using Google map API

Synthetic network 1 – A hypothetical supplier network

Visualization of the nodes of the network	**Visualization of the synthetic network**
	

Synthetic network 2 – A hypothetical distributor network

Visualization of the nodes of the network	**Visualization of the synthetic network**
	

6. CONCLUSIONS

Network analysis approaches are suitable for studying how patterns of inter-firm relationships in a supply network translate to competitive advantages through management of materials and information flow. This white paper presented an overview on network perspective for supply chain risk management. The capability to understand the implications of network structure and network relational dynamics in the context of disruption will enable managers to respond appropriately to disruptive supply chain events (Greening, 2011). This capability building deserves critical attention in the vulnerable and sensitive global economy. Such efforts would ensure an immaculate supply chain risk management during disruptions.

REFERENCES

Bellamy, M.A. and Basole, R.C (2012). "Network Analysis of Supply Chain Systems: A Systematic Review and Future Research," forthcoming, *Systems Engineering*, Vol. 16, Issue 2, pp. 1-20

Brookes, N.J,, Lewis P.A. (2006). "Globalising the Supply Chain: A Case-Study in the Premium

Aircraft Seating Business" *Moving Up The Value Chain: 13th International Annual EurOMA Conference:* University of Strathclyde, Glasgow, UK June 18-21, 2006

Greening, & Rutherford (2011). "Disruptions and supply networks: a multi-level, multi-theoretical relational perspective" *International Journal of Logistics Management, 22* (1), 104-126

Harland, C. (2003). Risk in supply networks Journal of Purchasing and Supply Management, 9 (2), 51-62

Kim et al, Structural investigation of supply networks (2011). "A social network analysis approach", Journal of Operations Management, 29 194–211

Lambert, D. & Cooper, M. (2000). "Issues in Supply Chain Management". *Industrial Marketing Management*, 29, p.65–83.

Mueller, Doreen Buergelt, and Linda Seidel-Lass (2007). "Supply Chains And Social Network Analysis", 1st International European Forum on Innovation and System Dynamics in Food Networks, February 15-17, Innsbruck-Igls, Austria

Nojan Najafi et al. (2011) "Supply Base Structuring: Introducing the Supply Network Model", http://publications.lib.chalmers.se/records/fulltext/local_150072.pdf

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