RiskVis: Supply Chain Visualization with Risk Management and Real-time Monitoring

Rick Siow Mong GOH, Zhaoxia WANG*, Xiaofeng YIN, Xiuju FU, Loganathan Ponnambalam,

Sifei LU, Xiaorong LI

Department of Computing Science
Institute of High Performance Computing, Singapore, 138632
*E-mail: wangz@ihpc.a-star.edu.sg

Abstract— **With increased complexity, supply chain networks (SCNs) of modern era face higher risks and lower efficiency due to limited visibility. Hence, there is an immediate need to provide end-to-end supply chain visibility for efficient management of complex supply chains. This paper proposes a visualization scheme based on multi-hierarchical modular design and develops a supply chain visualization platform with risk management and real-time monitoring, named RiskVis, for realizing better Supply Chain Risk Management (SCRM). A Supply Chain Visualizer (SCV) with a graphical visualization platform is mounted as a part of a SCRM management decision-making dashboard and it provides senior management a clearer view of supply chain operations in a local/regional/global setting. The platform not only displays spatio-temporal connectivity patterns of entities in a supply chain; it also accommodates real-time risk-related data collection and risk monitoring. The proposed platform offers the flexibility to be customized based on the user's requirements – to process and store the supply chain data in the server, visualize the supply chain data, network map, risk alert, and other information needed for SCRM. Supply chain decision makers can deploy it on the desktop or embed it into the company's enterprise applications in a front office environment for better managing risks of their supply chains.**

Keywords- Supply Chain Risk Management (SCRM); Multi-hierarchical modular design; Real-time risk monitoring; Supply chain networks; Supply Chain Visualizer (SCV); Visualization

I. INTRODUCTION

The increasing demand for mass customization in many industries and large magnitude of global sourcing have resulted in the complexity of today's supply chains and the high level of uncertainty and risks that companies are facing [1]. As supply chain networks (SCNs) are interconnected, non-linear, and stochastic in nature, these "risky" characteristics of the SCNs present even greater challenges in strategizing risk-mitigation measures during incidents [2]. With increased complexity and challenges in SCNs, it is desirable to go beyond the limited supply chain visibility [1] [2] [3] [4] in order to achieve better management of risks and improve efficiency. Thus, there is an immediate need to provide end-to-end supply chain visualization for efficient control and management of risks in complex supply chains.

About risks in supply chain networks, there are many definitions depending on their specific application and on their situation context [5] [6] [7]. Risk is sometimes interpreted as unreliable and uncertain sources creating supply chain interruption. As discussed in literatures, there are two important indicators in discussing risk: the outcome of risk impact and expectation of risk sources [7] [8]. Compared with negative consequences of impact, the expectation of risk is difficult to define [9] [10]. Most of the literatures agree that risk detection refers to detecting above patterns [9] [10] [19] [20]. Besides the discussion of predictability of low/high frequency of supply chain disruptions, real-time monitoring is critical and should be included in supply chain visualization for modern supply chain risk management for early alert and proactive risk management planning.

Supply chain visualization is an area of interest for both industry and academia attribute to the advent of advanced IT technologies [13] [19]. It can be the key enabler for managing business both within organizations and across organizational boundaries [4].

Many scientific contributions have indicated the importance of the supply chain visualization [3] [4] [14] [15] [16] [17]. Rule-based analysis techniques can be combined with a map-based representation interface to visualize the supply-chain information [14] [15]. A hybrid approach for combining the web service and computer agent technology was proposed to implement a Supply Chain Visualizer (SCV) [16] [17].

Modern technologies such as RFID and internet provide the potential to increase a supply chain visibility in a high-resolution manner [4]. The data and events of business processes can be analyzed in real time as the entire supply chain is now represented digitally. Detecting risk and tracing the location of the risky events in the actual supply chain networks should be included in supply chain visualization

platform. The use of internet, GPS techniques and other modern techniques make it possible for real-time collection of data [18] [19], which allows the performance of online data analytics to find risk patterns in time. The data can be further analyzed using an analytics engine to extract information about risk patterns in the system. This step is very important for developing proper strategies to deal with situations requiring continuous on-line monitoring so as to provide early warnings against failure or loss [18] [20] [21]. While there are numerous studies related to supply chain risk management, few studies deal with real-time implementation and visualization.

In our earlier work, a visualization platform has been developed for real-time anomaly detection and urban environmental management scheme by laveraging internet, sensor, GIS and other modem techniques [18]. The platform is able to i) display and manage the facility data including facility id, facility type and facility location; ii) real-time track and monitor anomalies; and iii) deploy staffs in a timely manner to handle the anomalies. The proposed scheme enables urban environment management to be more scientific, standardized and efficient [18].

Specification of visualization is a fundamental operation in visual analysis. The supply chain visualization designer must indicate which supply chain data is to be shown and the way they should be displayed. The visualization platform shall provide effective ways for users to view and explore large data sets of supply chain from varies data sources such as information of the focal company and possible substitution of suppliers [15] [16] [17]. From the input data, users should also be able to generate relevant statistics such as normalized values, statistical summaries, and aggregates by activating relevant functional modules [18] [20] [22] [23].

In this paper, we proposed a supply chain visualization scheme with risk management and real-time monitoring, named RiskVis, which is aimed to provide a live model of the supply chain network of an organization and a platform for risk analysis. RiskVis enables three key elements of supply chain risk mitigation [3]: i) better visibility of the entire supply chain and its happenings; ii) Scenario analysis to prepare the plan for supply chain risk mitigation; and iii) rapid responses to unplanned events. Through simulation and optimization engine running at the backend, the supply chain is simulated and analyzed under different market conditions and risk assumptions. By doing so, the vulnerability of the existing supply chain network is evaluated.

The RiskVis provides a visualization platform for supply chain risk management and real-time monitoring. A multi-hierarchical modular design is proposed for the scheme which reduces the complexity by distributing a complex system to several self contained modules. Based on the proposed scheme, a supply chain visualization platform which includes a graphical visualization platform mounted as a part of a management decision-making dashboard is developed. It allows senior management to have a clear overview of operations in a local/ regional and inter-enterprise setting for their theatre of operations. The platform not only displays temporal, spatial and connectivity patterns of supply chains, but can also realize real-time data collection and risk monitoring. This provides pertinent information for better management of their supply chains.

II. RISKVIS: SUPPLY CHAIN VISUALIZATION WITH RISK MANAGEMENT AND REAL-TIME MONITORING

A. Visualization

Visualization play important roles in exploring, analyzing, and presenting data [18] [22] [23] [24]. There are several definitions of visualization, depending on its context and applications. Generally, the term visualization may refer to information graphics visualization, computer graphics visualization, etc [18] [22] [25]. Information graphics are graphic visual representations of information, data or knowledge. Computer graphics visualization is any technique which creates images, diagrams, tables, animations, etc to display information or data and to communicate using a visualization interface.

Visualization can be implemented by various ways according to different real life applications [18] [22]. Jeffrey Heer and Ben Shneiderman presented a comprehensive taxonomy of visualization analysis towards successful analytic dialogues and the taxonomy consists of different task types, namely: to visualize, to filter, to sort, to derive, to select, to navigate, to coordinate, to organize, to record, to annotate, to share, and to guide [20]. A combination of some or all of these tasks may be required in the visualization application according to actual needs.

B. Hierarchical Design for RiskVis

A supply chain visualization platform is a tool with the required technologies to capture and analyze supply chain data to provide enhanced visibility for short and long term decision making [4]. For a supply chain visualization platform, supply chain visibility is the key enabler for managing the business within the organization and beyond [4]. Supply chain visualization is to provide convenient visibility tools to support supply chain managers [26].

A hierarchical system design can help realize a system that is scalable and easily maintained [18]. It is able to transfer a higher-complex problem to several lower-complex problems and solve the problem with manageable computational complexity [18] [21]. Therefore, we propose a multi-hierarchical modular design which combines with data analysis, network analysis and data mining techniques to solve the supply chain risk management challenges. The proposed RiskVis scheme is shown in Fig. 1 in which a SCV is seamlessly connected with a risk identification & mitigation module, a network analysis module, and other analysis modules.

These analysis modules provide technical support of data analyzing and processing for the SCV. The idea is consistent with previous research work [27] [28] and IBM supply chain write up [29], both of them indicated the importance of risk management & visualization.

This multi-hierarchical modular design for supply chain management reduces the complexity by distributing a complex problem to several self contained modules. Adding new function or features can be solved by adding a few new modules or sub-modules and modifying some existing ones. Modules can be maintained separately.

Fig. 1 shows the overview on the design of our proposed RiskVis scheme which is consistent with the future blueprint of implementation of the facilitative control tower [4] which serves as a decision making tool and hub for all supply chain network related information and analysis. As shown in the diagram, the SCV of the proposed RiskVis is designed to be a system with graphical user interface. The SCV acquires timely data from the data processing modules including risk identification and mitigation module and network-based analysis, modeling and simulation module. These modules collect, monitor and analyze critical items such as:

- Inbound and outbound logistics: it can help to detect the sign of delay of shipment 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.

This paper focuses on supply chain visualization with real- time risk monitoring. As shown in Fig. 1, a graphical interface is presented that provides real-time visualization of the supply chain network and risk related information. If a potential risk is identified, it will trigger the recording of data such as time, pattern, and location information, which will be displayed through the graphic interface at the same time. The framework design and the detail functions of the proposed RiskVis are described in the following sub-sections.

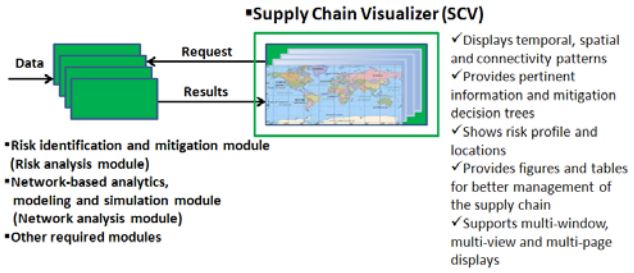

Figure 1 Hierarchical design for RiskVis scheme

C. *RiskVis framework*

As shown in Fig. 2, RiskVis framework has been proposed in which many modern techniques, such as internet, mobile communication, GPS, GIS, database and server technologies are employed and integrated to implement the detail functions of the system. These techniques are integrated together to enable the system to display risks dynamically and other required information to deal with the problems in a timely manner.

Both internal (focal company) and external (public domain) information can be manipulated and analyzed to extract valuable information for supply chain risk management.

c.1 External data and information provider

Public map servers such as Google map and Baidu map are the key information providers which provide geographical data interfaces. The supply chain network can be visualized by building applications on top of the maps. The geographic location of risks and disruptions can be highlighted to realize an interactive SCV and a management decision making dashboard. Furthermore, wireless communication provides another convenient way for data collection, transmission and processing.

Open source intelligence (OSINT) is knowledge and intelligence collected from public domain [30]. Open sources were observed to provide up to 90% of the information needed to meet most U.S. intelligence needs [31]. Apart from the traditional forms of media, there is explosion of information in the internet including the information disseminated by organizations and contents generated by individual web users. Intelligent web-spiders or bots can be deployed for data acquisition from internet. To extract relevant information from the acquired data, which is usually unstructured data, data-scrapping and analysis can be used to convert the unstructured data to structured data. Having structured data or information, they can be processed for intelligence.

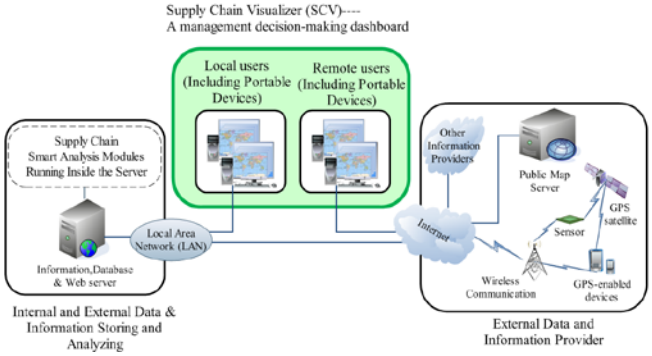

Figure 2 RiskVis framework

Supply chain risk related data such as natural disasters (earthquake, storm and so on) and the assessment of the stability of the work force of regions are real-time collected from information providers and monitored constantly. Real-time alerts will then be raised for critical risks that a focal company is facing.

c.2 Internal and external data & information storing and analyzing

Interfaces are created for the system to accommodate various supply chain and risk related data. It includes the supply chain network configuration data and other information of the focal company, such as the best practices to isolated problems and unplanned disruptions, alternative suppliers and transportation modes, and other private and confidential information.

Internal and external data & information is stored in a database and web server which can be analyzed by our supply chain smart analysis modules that are compiled and implemented in the same server cluster. The server cluster acts as a supply chain data repository to serve various functions that are required by the SCV as shown in Fig. 2. Accessing the system functionality can be achieved through local computers or remote access equipments. SCV is the core part of the whole system and is described in the following sub-section.

c.3 SCV of RiskVis

SCV, which is the core of the RiskVis, is to display temporal, spatial and connectivity patterns of supply chains. As illustrated in Fig. 3, the RiskVis is designed to be a system with a SCV. Through the graphical user interface of the SCV, supply chain managers can monitor, measure and manage the respective supply chain. The graphical user interface can make the supply chain risk and disruption visible across the SCNs. The detail functions of the graphical user interface are listed below:

- ✓ Displays temporal, spatial and connectivity patterns
- ✓ Provides pertinent information and mitigation decision trees
- ✓ Shows risk profile and locations
- ✓ Provides figures and tables for statistic data and risk map for better management of the supply chain
- ✓ Supports multi-window, multi-view and multi-page displays

Fig. 3 shows the main user interface of the SCV, which consists of two parts: function selection frame on the left side and information-viewing frame on the right side. The function selection frame shows the different selections through different buttons and other optional controls while the information-viewing frame shows the corresponding maps, risks, alert and other details according to the selected information in the function selection frame.

The detailed functions are reflected by different pages, such as displaying the supply chain network, detailed data presentation and analysis results, locating various risks, and raising real-time risk alerts. 'Supply chain map' web page displays an end-to-end supply chain network including vendors, manufacturing plants, assembly plants, logistic companies, distribution centers and retailers/customers, and the geographic location of individual node. Key areas of interest along the supply chain can be defined and simulations can be triggered to derive the short-term or long-term mitigation plan for various disruptions. Figs. 3-6 illustrate some key functions of the RiskVis. Tiers of vendors and customers are summarized into a single diagram with highlighted focal company (Fig. 3). Through an offline simulation and optimization engine running at the backend (system integration design and development is on-going currently), the vulnerability of the existing supply chain network and the degree of importance of the links and nodes to the supply chain is evaluated as depicted by the thickness of the lines between nodes and the numbers in the center of icons. The significant links and nodes which reflect the most critical areas of the supply chain can be constantly monitored for any unplanned disruptions.

The risk map displays real-time risk related information, such as natural disasters as shown in Fig. 4, which is collected from open source / public domain and the supply chain network itself. Real-time earthquake information and twitter data are currently collected for analysis. The yellow circle is an indication of the number of twitter data collected around the region of an earthquake which may reflect the damage of the earthquake to some extent. Fig. 5 shows an illustration of the risk alert information. Not only the text information, but also the map and other parameter information, such as locations and historical data can be displayed according to the user's requirements. Fig. 6 further illustrates the consequences of the last alert. It warns that the production rate will be affected if the alert is ignored. An alternative vendor for mitigation has been suggested through simulation and analysis.

In the previously designed and developed visualization framework [18], all types of interactive dynamics presented by Jeffery Heer and Ben Shneiderman [20] are realized and implemented as shown in Table 1 which are also interactive dynamic functions of the proposed RiskVis.

III. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a supply chain visualization platform (RiskVis) based on multi-hierarchical modular design for overcoming supply chain risk management challenges. By employing the multi-hierarchical modular design concept, we have reduced the

platform complexity by distributing the complex visualization system to several self-contained modules. In addition, it maintains the flexibility to incorporate new functions or features for specific supply chain risk management tasks in the near future.

In our proposed RiskVis, real-time risk monitoring has been taken into consideration for providing prompt alert and assisting proactive risk management planning. The developed RiskVis facilitates the monitoring and collection of real-time risk information which includes internal (focal company and its supply chain) and external (public domain) information.

The proposed RiskVis provides a platform to better manipulate and analyze the data and extract valuable information for supply chain risk management through analysis modules. Moreover, RiskVis could provide useful reference information for supply chain design and planning by analyzing the risk-related supply chain data, such as natural disaster data and their historical impacts on supply chains.

TABLE I. THE INTERACTIVE DYNAMIC FUNCTIONS [18] [20]

• Functions provided through the graphic user interface
• Receive and show real time information
• Organize multiple windows
• Record analysis histories
• Filter out data to focus on relevant items
• Sort items to expose patterns
• Derive values of parameters from the database
• Select one or more parameters, and show statistical analysis result
• Add, delete, edit the selected data
• Inquire the real-time location and condition information of the selected items
• Map the data according to various functions
• Show different icons according to different items (such as different risks)
• Share views and annotation to enable collaboration
• Guide users through analysis tasks
• Select items to highlight, manipulate, zoom in or zoom out
• Navigate to examine high level patterns and low level details

Figure 3 User interface of the RiskVis

Figure 4 Display real-time nature disaster, such as earthquake

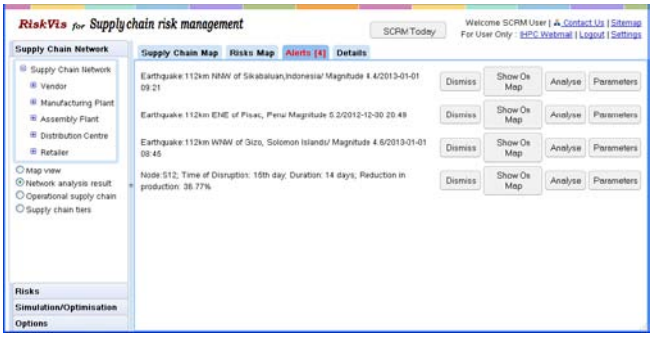

Figure 5 Illustration of alerts

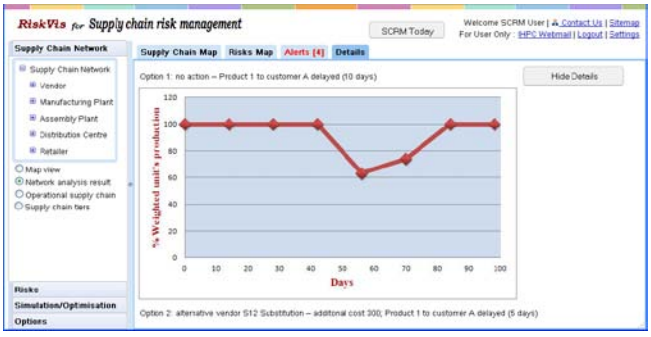

Figure 6 Simulation results of risk/alert analysis

Besides supply chain visualization and real-time risk monitoring, risk identification is the next critical step of supply chain risk management. The risk-related supply chain data collected and accumulated monitoring data should be analyzed further for risk identification, assessment and management. This therefore indicates the importance of real-time data collection and analysis which will be enhanced further in our future work.

ACKNOWLEDGMENT

The work is supported by a research grant from Science and Engineering Research Council (SERC), A*STAR (Title of Supported Project: Master Facilitative Control Tower for Risk Management of Complex Supply Chains and Ref Number: 1121790043).

REFERENCES

[1] Y. K. Tse and K. H. Tan, "Managing product quality risk and visibility in multi-layer supply chain," *International Journal of Production Economics*, vol. 139, no. 1, pp. 49-57, 2012.

[2] C. Speier, J. Whipple, D. Closs, and M. Voss, "Global supply chain design considerations: Mitigating product safety and security risks," *Journal of Operations Management*, vol. 29, no. 7–8, pp. 721-736, 2011.

[3] LLamasoft, "Three Elements of a Truly Effective Supply Chain Risk Management Strategy," *http://www.llamasoft.com/wp-content/uploads/2012/12/WP-Supply-Chain-Risk-Management-US.pdf, [cited 4 January 2013]*, 2012.

[4] B. Griffin-cryan, "Global supply chain control tower," *http://www.capgemini.com/m/en/tl/Global_Supply_Chain_Control_Towers.pdf, [cited 5 may 2012]*, 2012. .

[5] O. Lavastre, A. Gunasekaran, and A. Spalanzani, "Supply chain risk management in French companies," *Decision Support Systems*, vol. 52, no. 4, pp. 828-838, Mar. 2012.

[6] A. R. Singh, P. K. Mishra, R. Jain, and M. K. Khurana, "Design of global supply chain network with operational risks," *The International Journal of Advanced Manufacturing Technology*, vol. 60, no. 1–4, pp. 273-290, Sep. 2011.

[7] A. Norrman and R. Lindroth, "Categorization of Supply Chain Risk and Risk Management," *Supply Chain Risk (Ed. Clare Brindley)*, pp. 14-27, 2004.

[8] O. Tang and S. N. Musa, "Identifying risk issues and research advancements in supply chain risk management," *International Journal of Production Economics*, vol. 133, no. 1, pp. 25-34, 2011.

[9] P. Kouvelis, C. Chambers, and H. Wang, "Supply Chain Management Research and Review, Trends, and Opportunities," *Production and Operations Management*, vol. 15, no. 3, pp. 449-469, 2006.

[10] I. Manuj and J. T. Mentzer, "Global supply chain risk management strategies," *International Journal of Physical Distribution & Logistics Management*, vol. 38, no. 3, pp. 192-223, 2008.

[11] S. M. Wagner, C. Bode, and P. Koziol, "Supplier default dependencies: Empirical evidence from the automotive industry," *European Journal of Operational Research*, vol. 199, no. 1, pp. 150-161, Nov. 2009.

[12] S. M. Wagner and N. Neshat, "Assessing the vulnerability of supply chains using graph theory," *International Journal of Production Economics*, vol. 126, no. 1, pp. 121-129, Jul. 2010.

[13] T.-ming Choi, "Coordination and Risk Analysis of VMI Supply Chains With RFID Technology," *IEEE Transaction on Industrial Informatics*, vol. 7, no. 3, pp. 497-504, 2011.

[14] A. Ilic, T. Andersen, and F. Michahelles, "Increasing Supply-Chain Visibility with Rule-Based RFID Data Analysis," *IEEE Internet Computing*, vol. 13, no. 1, pp. 31-38, 2009.

[15] M. Barratt and A. Oke, "Antecedents of supply chain visibility in retail supply chains: A resource-based theory perspective," *Journal of Operations Management*, vol. 25, pp. 1217-1233, 2007.

[16] J. U. Min and H. Bjornsson, "Construction Supply Chain Visualization Through Web Services Integration," *http://cife.stanford.edu/sites/default/files/TR149.pdf*, 2004.

[17] E. Vezzetti, "Product lifecycle data sharing and visualisation: Web-based approaches," *The International Journal of Advanced Manufacturing*, vol. 41, no. 5–6, pp. 613-630, 2009.

[18] Z. Wang, C. S. Chong, R. S. M. Goh, W. Zhou, D. Peng, and H. C. Chin, "Visualization for Anomaly Detection and Data Management by Leveraging Network, Sensor and GIS Techniques," *IEEE 18th International Conference on Parallel and Distributed Systems (ICPADS)*, pp. 907 - 912, 2012.

[19] WebMapSolusions, "Mobile ArcGIS: From Paper to GPS Data Collection," *http://www.webmapsolutions.com/mobile-arcgis-paper-gps-data-collection, [Cited 5 May 2012]*.

[20] J. Heer, B. Shneiderman, and C. Park, "Interactive Dynamics for Visual Analysis: A taxonomy of tools that support the fluent and flexible use of visualizations," *Communications of the ACM*, vol. 55, pp. 45-54, 2012.

[21] C. S. Chang, Z. Wang, F. Yang, and W. W. Tan, "Hierarchical Fuzzy Logic System for Implementing Maintenance Schedules of Offshore Power Systems," *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 3-11, Mar. 2012.

[22] J. Kehrer and H. Hauser, "Visualization and Visual Analysis of Multi-faceted Scientific Data: A Survey.," *IEEE transactions on visualization and computer graphics*, vol. 19, no. 3, pp. 495-513, Apr. 2013.

[23] R. Kruse and M. Steinbrecher, "Visual data analysis with computational intelligence methods," *Bulletin of the Polish Academy of Sciences: Technical Sciences*, vol. 58, no. 3, pp. 393-401, Sep. 2010.

[24] J. Gan and C. Norman, "2012 Visualization Challenge," *Science*, vol. 339, no. 1, p. 509, 2013.

[25] Wikipedia, "Visualization (computer graphics)," *http://en.wikipedia.org/wiki/Visualization_(computer_graphics), [Cited 4 April 2012]*.

[26] A. Ilic, T. Andersen, F. Michahelles, and E. Fleisch, "Analyzing Product Flows with the Supply Chain Visualizer Demo at Internet of Things Conference 2008 , Zurich," *Development*, pp. 1-5, 2008.

[27] K. B. Hendricks, V. R. Singhal, and R. Zhang, "The effect of operational slack, diversification, and vertical relatedness on the stock market reaction to supply chain disruptions," *Journal of Operations Management*, vol. 27, no. 3, pp. 233-246, Jun. 2009.

[28] B. Tomlin, "On the value of mitigation and contingency strategies for managing supply chain disruption risks," *Management Science*, vol. 52, no. 5, pp. 639-657, 2006.

[29] IBM, "The Smarter Supply Chain of the Future," *http://www.ibm.com/expressadvantage/mx/descargas/GBE03183USEN.pdf, [Cited 1 April 2012]*, 2009.

[30] M. Glassman and M. J. Kang, "Intelligence in the internet age: The emergence and evolution of Open Source Intelligence (OSINT)," *Computers in Human Behavior*, vol. 28, no. 2, pp. 673-682, 2012.

[31] C. Pallaris, "Open Source Intelligence: A Strategic enabler of National Security," *Center for Security Studies (CSS) Analyses in Security Policy*, vol. 3, no. 32, pp. 1-3, 2008.