SUPPLY CHAIN VULNERABILITY AND RESILIENCE: A STATE OF THE ART OVERVIEW

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ABSTRACT
The main objective of this paper is to provide the reader with a state of the art on the supply chain resilience. Markets globalization and global supply chains have to be regarded as business opportunities of economic development for each supply chain actor, but at the same time, they introduce a number of risks and vulnerabilities that affect the capability of the supply chains to maintain equilibrium states over long period of time. The importance of supply chain resilience and its connection with risks and vulnerabilities is underlined. Several case studies are presented in the context of supply chain resilience. Two different frameworks for categorizing supply chain risks are presented and the importance of information sharing and visibility along the supply chain is highlighted. Finally in the context of supply change management, Modelling & Simulation is presented as an ideal framework for experiencing critical events, understanding the effects of risks on supply chain vulnerability and testing supply chain resilience.

Keywords: Vulnerability, Security, Resilience, Supply Chain Management, Supply Chain Change Management

1. INTRODUCTION

Starting from 1990 a continuous markets globalization process has taken place involving supply chains and causing a remarkable extension of goods, services, information and financial flows. Before September 11 supply chain change management took into consideration above all robustness and costs efficiency neglecting or slightly considering supply chain risks, security and vulnerability. The supply chain robustness is defined as the capability to keep under control outputs variability (supply chain performances as service level, total costs and so on) in correspondence of high inputs variation (Christopher and Rutherford, 2004). Markets globalization, September 11 (or similar events), natural disasters effects (i.e. Katrina hurricane in New Orleans) have strongly underlined the need to consider, as further priority aspect in supply chain management, the "continuity" in correspondence of catastrophic events or disruptions. Supply chain disruptions happens under the effects of specific risks that can be internal to the company being considered, external to the company or external to the supply chain.

As reported in "Understanding Supply Chain Risk: A Self Assessment Workbook" (2003), terrorist attacks, wars, politic problems, natural disasters should be considered as risks external to the supply chain. Risks coming from the market or from suppliers should be considered as external to the company and internal to the supply chain; finally risks related to processes and activities should be considered as internal to the company (Sheffi, 2006; Sheffi, 2005-a).

In such a context the supply chain capability to assure continuity can be expressed in terms of resilience. The resilience is defined as the system ability to reach its equilibrium state (or another more desirable equilibrium state) after being disturbed by external or internal factors. As reported in "Creating a Resilient Supply Chains: A Practical Guide" (2003) the resilience definition takes into consideration the following aspects: supply chain flexibility, agility, velocity, visibility and redundancy. Before getting into details of the elements affecting the supply chain resilience, let us give a brief overview of the paper. Section 2 presents a list of research works focused on supply chain vulnerability, security and proposes some real case studies in the context of supply chain resilience. Section 3 describes the most important frameworks proposed in the literature for categorizing supply chain risks and highlights the importance of information sharing and visibility along the supply chain. Section 4 proposes the Modelling & Simulation based approach as decision support tool for improving supply chain resilience. Finally the last section reports the conclusions and the research activities still on going.

2. SUPPLY CHAIN RESILIENCE

2.1. Some definitions of resilience

According to the on-line *American Heritage dictionary*, resilience is the (i) "ability to recover quickly from

illness, change, or misfortune"; (ii) "the property of a material that enables it to resume its original shape or position after being bent, stretched, or compressed".

According to the *on-line Merriam-Webster* the resilience is the (i) "an ability to recover from or adjust easily to misfortune or change"; (ii) "capability of a strained body to recover its size and shape after deformation caused especially by compressive stress".

The *on-line Compact Oxford Dictionary* defines resilience as the (i) "ability to withstand or recover quickly from difficult conditions (of a person)"; (ii) "the ability to recoil or spring back into shape after bending, stretching, or being compressed".

The definitions reported above refer to resilience as a property (of a person or material). Analogously we can say the resilience is a critical property that, in a context of supply chain change management, allows to the supply chain to react to internal/external risks and vulnerabilities quickly recovering an equilibrium state capable of guarantying high performance and efficiency levels.

2.2. Main factors affecting supply chain resilience

As reported into the introduction the most important elements affecting supply chain resilience are: flexibility, agility, velocity, visibility and redundancy.

Sheffi (2006) says that flexibility helps companies in correctly answering to markets variability and it can be obtained simultaneously using some factors as concurrent processes, final goods completing postponement inside the supply chain, strategies sharing with suppliers. The author also reports the case of the Hewlett-Packard printers: the completion of each printer (in terms of power supply, wall plug and instructions language) is delayed until the reception of the orders coming from different European countries. In that case the HP printer was ad-hoc designed for the postponement of the operations regarding power supply, wall plug and instructions language.

Christopher and Rutherford (2004), the report "Creating a Resilient Supply Chains: A Practical Guide" (2006) propose an accurate definition and description of the supply chain agility, velocity, visibility and redundancy. The authors define the agility as the company capability to quickly respond to unforeseen and unpredictable demand/supply markets changes. Note that the agility of a company also depends on the agility of all the actors involved in the supply chain. The velocity must be interpreted as time required for moving goods along the supply chain. The velocity is usually measured in terms of lead times. The visibility is the capability of the company to see all the information regarding the flow of products, information and finances both downstream and upstream along the supply chain. The redundancy is the augmentation of capacity and inventory in each node of the supply chain for facing supply chain disruption events. Note that, as underlined by Sheffi (2006), a company that hold extra inventory and capacity can incur in costs augmentation moving against all the principles dictated by just-in time approaches, lean processes and six-sigma methodology. Further aspects to be considered for supply chain resilience are the culture corporate and information sharing among the supply chain actors (Stenger et al., 2000).

2.3. Some research works on supply chain vulnerability

After the 9/11 attacks to the twin towers, the number of research works in the filed of supply chain security and vulnerability has strongly increased. In effect the 9/11 event is considered as one of the most important supply chain disruption event due to both short and long period economic effects.

In the sequel, we enumerate and provide short descriptions of some significant research works considering different types of risks affecting the supply chain. Even before 2001, the supply chain vulnerability and security were considered as an important topic as testified by the research work carried out by Choi and Hartley (1996), Christopher (1998), Braithwaite and Hall (1999). The first work presents and compares different methodologies for suppliers base selection; the second research work focalizes on strategic approaches for reducing costs within the supply chain; finally the last research work faces the problem of critical decisions (in terms of business risks) in supply chain management.

Peck and Juttner 2002 propose a survey on the main supply chain risks also considering the companies reactions for reducing/eliminating risks. Pai et al. (2003) present some methods for risks analysis based on Bayesian Networks, Fuzzy Logic and a combined approach of both.

A number of research studies introduce the concept of supply chain resilience. Such studies propose a map of supply chain vulnerabilities and classify supply chain risks in different phenomena (i.e. Hurricanes, Earthquakes), incidents (i.e. Exxon Valdese, Chernobyl), terrorist attacks (9/11 USA, 3/11 Spain), market globalization (i.e. strikes, new security procedures, insolvency).

For further information refer to Sheffi (2005-a), Sheffi (2005-b), Sheffi and Rice (2005), Christopher and Rutherford (2005), Sheffi (2006).

Concerning risk analysis and categorization, Wu et al. (2006) propose a risk analysis in the inbound supply chain identifying, evaluating and validating supply chain risks. Finally Gaonkar and Viswanadham (2004) present a model of a conceptual framework for supply chain risk categorization at strategic level.

Longo and Mirabelli (2008) focalize on the effects of demand/supply variability by using a supply chain management tool based on Modelling & Simulation (the aim is to understand the impact of such factors on each supply chain stage, i.e. distribution centers, stores, etc.). Still on demand/supply variability De Sensi et al. (2007) present and compare different inventory control policies considering market demand and lead times constraints. Nagurney and Matsypura (2005) propose a model of a

three stages supply chain able to monitor network nodes competitiveness.

The scientific researches carried out by Sun and Yu (2005) and Deleris and Elkins (2004) respectively regard the impact of catastrophic events on supply chain contracts and probability distribution of losses caused by such events.

Further studies on supply chain vulnerability reduction regard the information sharing. In particular Sheffi (2005-a) and Suo and Jin (2004) states that one of the critical problems of the information sharing is the Bullwhip effect that is the amplification of the demand uncertainty moving back along the supply chain. Concerning the Bullwhip effect further information can be found in Lee et al. (1997).

It's important to stress that several scientific researches on supply chain vulnerability and risks management have involved big companies operating in the most important sectors or have been developed considering specific supply chain sectors. Hopper and Beck (2004) propose a study on supply chain risks in the automotive sector, Agrell et al. (2004) in the telecommunication sector. Some examples of research studies in specific supply chain sector regard marine security levels analysis in marine terminals (Barnes and Oloruntoba, 2005; Longo and Bruzzone, 2005; Longo et al. 2005, Bruzzone et al. 2005), costs evaluation for disruptive events in railways networks (Mirabelli et al. 2005), innovative tools for risk management in the aeronautical sector (Haywood and Peck, 2003) and the introduction of strategies for minimizing and contrasting the effects of the new products from foreign markets/countries in the textile sector (Chandra, 1999).

2.4. Supply Chains disruption: some real case studies

As mentioned in the previous section supply chain risks have to be regarded as critical factors affecting the supply chain management (Sheffi, 2005-a; Peck and Juttner 2002; Pai and Zhou 2003; Wu et al. 2006). Supply chain risks are situations of potential danger that could happen out of control affecting consistently supply chains, above all in case of just in time synchronized production sites in different parts of the world, stock minimization and lead time reduction. Sheffi (2006) reports clear examples of supply chains disruption. After the 9/11 terrorist attack, the U.S. government shutdown the Canadian and Mexican borders forcing Chrysler and Ford to an intermittent production. Toyota supply chain thanks to redundancy in terms of multiple suppliers and multiple stocks was more resilient than Chrysler and Ford supply chains. Toyota was capable of assuring a greater "continuity" in correspondence of the terrorist event and, above all, in correspondence of the U.S. government overreaction. An analogous situation was that after the Taiwan earthquake that stopped for a while the supply of semiconductors from that country. Also in this case the supply chains of some companies, such as Dell, were more reactive (more resilient) than other companies such as Apple.

Other examples of external risks causing supply chains disruption are strikes, suppliers' insolvency or fast withdrawal of already distributed products. Examples of fast withdrawal of already distributed products are: (1) the Mad Cow Disease (1996); (2) the high levels of Dioxin in Coca-cola drinks, Belgium (May 1997); (3) the high levels of Dioxin in Belgium Poultry (July 1999); (4) the diethylene glycol in the Colgate toothpaste (July 2007); (5) the Mattel Lead Contaminated toys (August 2007).

Consider as further examples of the impact of risks on supply chains vulnerability and resilience the Nokia-Ericsson case and the Land Rover case (further information can be found in "Creating a Resilient Supply Chains: A Practical Guide" (2003). The 17th of March 2000, due to a problem to the power lines of a Philips Electronics plant, millions of silicon wafers and chips for Nokia and Ericsson mobile phones were destroyed (at that time Philips was the sole supplier for both Nokia and Ericsson and the worldwide demand for mobile phones was booming). Philips communicated to Nokia and Ericsson that the problem was totally under control. Nokia decided to investigate deeply the problem and discovered that the situation was so critical that the supplies would be disrupted for months. Consequently Nokia started to ask additional supplies to the other Philips plants and decided to modify its mobile phones in order to include different types of silicon wafers and chips. On the contrary Ericsson did not investigate the problem, trusting its first and sole supplier. When Ericsson understood that the supplies were destroyed for months was too late for finding additional suppliers. The economic impact for Ericsson in terms of loss revenues were estimated in about 400 millions of dollars and Nokia cemented its position as leader of the mobile phones market.

In 2001 the sole supplier of Land-Rover for its Land Rover Discovery was the UPF-Thompson that, at the end of 2001 became insolvent. Land Rover was able to afford production stop but the economic impact was sudden and severe.

In both cases the main problem was the suppliers base strategy. Just-in time approaches and costs minimization require a low number of suppliers (the best situation is one supplier for each specific component or service). In this case the entire supply risk falls upon that supplier strongly affecting the supply chain resilience.

3. SUPPLY CHAIN RISK ANALYSIS

Reducing supply chain vulnerability and improving supply chain resilience requires to categorize and analyze risks as well as requires to understand the effect of information sharing on visibility along the supply chain.

3.1. Categorizing the supply chain risks

Mason et al. (1998) and Cristopher and Peck (2004) propose a framework for categorizing supply chain risks subdivided in five different categories:

- process risks internal to the company;
- control risks internal to the company;
- demand risks external to the company and internal to the supply chain;
- supply risks external to the company and internal to the supply chain;
- environmental risks external to the supply chain.

Note that a company is the union of different processes and activities that aim, in the long period, at increasing the value added of the business strategies. Process risks may affect all the activities carried out by the company, from the manufacturing production to quality levels, from warehouses management to transportation activities.

Control risks are strictly related to Process risks. In effect processes and activities are governed by rules and controls. The warehouse management is performed by using inventory control policies, the manufacturing process in a job shop is ruled by shop orders scheduling, the quality levels depends (among the others) on the methodology being used for improving quality. In other terms each process inside a company has specific controls and rules. Wrong controls and rules act as risks affecting the performances of the company and its resilience (i.e. wrong inventory control policies and/or demand forecast methodologies, inadequate production planning, wrong corporate culture during the implementation of quality methodologies and systems, etc.).

Demand risks usually involve the flow of products, information and finances downstream the company being considered. Such risks are related to the powerlessness of the company (due to unpredictable events) to satisfy market demand and also include demand forecasts risks and Bullwhip effect. Note that among the consequences of markets globalization the most important affecting the demand forecasts risks are the growing products assortment and the shorter products life cycle. In such a context classical demand forecasting techniques may result inadequate. In effect numerous research works have been proposed in order to consider higher items aggregation levels and more reliable forecast models (two different examples are respectively reported in Dekker et al., 2004 and Zotteri et al., 2005).

Supply risks involve the flow of products, information and finances upstream the company being considered. Such risks are related to suppliers' reliability and suppliers' base selection. Note that suppliers should be able to delivery the right products at the right place and time. The Nokia-Ericsson and the Land Rover cases (presented in section 2.1) show that the supply risks cause the supply chain disruption in case of supplier's insolvency or inability to deliver the materials over a long period of time.

Finally the environmental risks have to be regarded as uncontrollable and sometime unpredictable events that strongly affect the supply chain vulnerability and resilience. Among the others the most important are natural disasters, wars, terrorist attacks, political and social disorders. The 9/11 attacks in USA demonstrated the vulnerability of the U.S. economy to shutdown the transportation system, and especially the vulnerability of extended supply chains and trans-border just-in-time manufacturing systems. Consider for instance the case of container terminals security. Container terminals are the most important rings of the cargo supply chain. Before 9/11, about 2% of incoming containers were physically opened and inspected and this percentage has been increased to 5.4% with dramatic effects on supply chain performances.

Another alternative framework for categorizing supply chain risks can be found in "Creating a Resilient Supply Chains: A Practical Guide", (2003). The authors recognize four levels of risks, named as follows:

- Process and Value stream (first level);
- Assets and Infrastructure Dependencies (second level);
- Organizations and Inter-Organizational Networks (third level);
- Environment (fourth level).

The risks of the first level regard all the processes and the value added both upstream and downstream the company being considered. In effect in the first level the problem of the supply chain vulnerability and supply chain risks should be faced by considering the entire supply chain. For a better understanding of the first level risks consider that the "process risks", described in the framework proposed by Mason et al. (1998) and Cristopher and Peck (2004), have to be regarded as extended to the entire supply chain, applied to each actor of the supply chain. The reduction of the first level risks requires high levels of trust among the supply chain actors and in turn this means information sharing and high visibility along the entire supply chain.

The risks of the second level regard the assets and the infrastructure dependences. A supply chain is made up by links and nodes. In terms of products flows, nodes are distribution centers, plants, terminals, stores, whilst links are roads, waterways, rails, etc. In terms of information flows, nodes are ICT platforms while links are the communication networks that connect, at each level (national, international, intercontinental), the ICT platforms. The continuity of the operations in each node and/or link (risks reduction and resilience enhancement) should be assured by all the managers, operators and workers at each stage of the supply chain. The second level risks underline the importance of the human factor for supply chain management.

The risks of the third level regard the supply chain strategic management. The relationships between the

supply chain actors are ruled by the position of power of each actor. In a globalized market the high levels of competitiveness usually lead companies to fight each other even in the same supply chain, pursuing different objectives or abusing of the own position of power. Once again the case Nokia-Ericsson shows how Philips (the sole supplier of both Nokia and Ericsson abused of its position by minimizing the problem to its plant).

Finally the risks of the fourth level are the same environmental risks described in the framework proposed by Mason et al. (1998) and Cristopher and Peck (2004).

A toolkit for supply chain risks categorization, analysis can be found in "Creating a Resilient Supply Chains: A Practical Guide" (2003). Among the others, the authors propose Scenario Planning, Brainstorming, Failure Mode and Effects Analysis, Flowcharting, Pareto Analysis, Modelling & Simulation as powerful tools that can help the managers in supply chain risks management.

4. SUPPLY CHAIN CHANGE MANAGEMENT BASED ON MODELING & SIMULATION

4.1. The Supply Chain Change Management

It is now well clear that supply chain is continuously changing over the time. A part of the effort of supply chain managers should be devoted to supply chain change management. Each new business opportunity is always characterized by risks that strongly affect supply chain vulnerability and resilience. In effect the supply chain change management should pursue optimal trade-offs between technical-economic advantages (costs reduction, productivity increase) and resilience (considered as risk levels and vulnerability variation) by considering the company and its processes, the rules and the controls, the organizations, the infrastructures, the business strategies and the environmental conditions. Such optimal trade-offs can be obtained by performing the following actions:

- tactical, strategic and operative analysis of the decisions tools used for supply chain change management (from the perspective of resilience);
- enhancement of the decisions tools for supply change management including specific toolkits for risks categorization and analysis;
- development of decisions models and operative tools for supply chain change management in order to reduce vulnerability and increase resilience and security;
- scenarios planning and development for decisional models and operative tools verification, validation and testing (VV&T).

Taking into consideration such actions, the supply chain change management devoted to support and improve supply chain resilience should be subdivided in four main stages. The first step is a survey on supply chain change management considering strategic business decisions and the effects of such decisions on supply chain vulnerability. The second stage identifies the actual guidelines followed in supply chain vulnerability management. According to these phases it will be possible to categorize risks at every level as well as to guarantee, using crossing and comparative analyses, existing tools improvement or to introduce new tools in order to increase supply chain flexibility and agility.

The third stage proposes the integration of the previous results together with methodologies capable of guarantying supply chain low risks and vulnerability levels in order to develop decisional models and operative tools for supply chain change management.

To better understand the fourth and last step, it is necessary to underline that a change process pushes the company to migrate from the actual scenario or context to a different one; the characteristics of such new scenario depend on controllable and uncontrollable factors (for example, the market evolution dynamics is an uncontrollable factor while manufacturing process reliability is a controllable factor). As consequence, the definition and the analysis of the change processes must develop several scenarios and/or evolutionary contexts that have to be used as case studies for verification, validation and testing of the decisional models developed.

4.2. Modeling & Simulation for supporting supply chain resilience

Modeling & Simulation (M&S) provides an ideal framework for experiencing critical events, understanding the effects of risks on supply chain vulnerability, testing scenarios and evolutionary contexts, measuring supply chain resilience.

The development of a decision support tool, based on M&S to be used for supporting the enhancement of supply chain resilience should follow the four steps described in the previous section. The change processes management should take into consideration the identification of cause-effect relations that connect strategic business choices to elements of vulnerability, security and resilience of supply chains. After the development of decision models for supply chain change management in the framework of resilience a framework capable of hosting the decision models should be implemented, opportunely integrated in modelling and simulation tools. A simulator should combine the different models to operate as a complete and process integrated decisional tool (i.e. a federation in an High Level Architecture-HLA environment capable of integrating the modules such as demand forecasting, logistic flows, production risks, etc.).

Longo & Massei (2008) propose the architecture of an M&S framework based on HLA for integrating different decision models for supporting supply chain resilience and vulnerability. Bruzzone et al. (2006) propose a demonstrator that uses M&S for providing and analyzing a crisis scenario of hurricane event. The

simulation allows to understand the relations between the crisis scenario and the transportation activities with special attention to logistic flows and indirect costs.

5. CONCLUSIONS

The paper proposes an exhaustive state of the art overview on supply chain vulnerability and resilience. The study of the research works developed during the last years, the analysis of the real case studies allows to understand that supply chain resilience is a quite complex topic involving different research area. Among the others the most important research areas are:

1. Supply chain vulnerability, security and resilience management
2. Methods for demand forecasting and supply risks analysis in supply chain
3. Information management and visibility along the supply chains
4. Supply chain Life Cycle Costing
5. Modelling & Simulation devoted to support supply chain resilience.

In addition note that the concept of resilience becomes more important for Small & Medium Enterprises (SMEs). In effect big companies usually have management tools for facing supply chain risks and reducing vulnerabilities. The most challenging objective is to develop an integrated tool that allows SMEs to react in an agile, lean and flexible way to the events that characterize the evolution of competitive and international markets (both internal or external to the supply chain, controllable or not, unexpected, destructive or catastrophic).

REFERENCES

Agrell, P. J., Lindroth, R., Norrman, A., 2004. Risk, information and incentives in telecom supply chains, *International Journal of Production Economics* 90, pp. 1-16.

American Heritage Dictionary: resilience, Available from: http://www.merriamwebster.com/dictionary/resilience

Barnes, P., Oloruntoba, R., 2005. Assurance of security in maritime supply chains: Conceptual issues of vulnerability and crisis management. *Journal of International Management*, 11 pp. 519-540.

Braithwaite, A., Hall, D., (1999). Risky business? Critical Decisions in supply chain management, Part 2, *Supply Chain Practice*, 1(3), pp. 44-58.

Braithwaite, A., Hall, D., 1999. Risky business? Critical Decisions in supply chain management, Part 1, *Supply Chain Practice*, 1(2), pp. 40-47.

Bruzzone, A. G., Longo, F., Papoff, E., 2005. Metrics for global logistics and transportation facility information assurance, security, and overall protection. *Proceedings of the European Simulation Symposium*.

Bruzzone, A.G., Longo, F., Massei, M., Saetta, S., 2006. The vulnerability of supply chains as a key factor in supply chain management. *Proceedings of the Summer Computer Simulation Conference*, Calgary (Canada).

Chandra, P., 1999. Competing through capabilities: strategies for global competitiveness of the Indian textile industry. *Economic & Political weekly*, 23.

Choi, T. Y., Hartley, J. L., 1996. An exploration of supplier selection practices across the supply chain. *Journal of operations Management*, 14 pp. 333-343.

Christopher, M., 1998. Logistics and Supply Chain Management: Strategies for reducing costs and Improving Service, *Financial Times, Prentice Hall*.

Christopher, M., Rutherford, C., 2004. Creating a supply chain Resilience through Agile Six Sigma, *Critical Eye Publications LTD*, pp. 24-28.

Christopher, M.., Peck, H., 2004. Building the resilient supply chain. *International Journal of Logistics Management*, 15(2), pp. 1-13.

Compact Oxford Dictionary: resilience. Available from: http://www.askoxford.com/dictionaries/compact_oed/?view=uk

Creating a Resilient Supply Chains: A Practical Guide, 2003. Report produced by the *Centre for Logistics and Supply Chain Management, Cranfield school of Management*.

De Sensi, G., Longo, F., Mirabelli, G., 2007. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. *International Journal of Production Research*, doi: 10.1080/00207540701528776.

Dekker, M., Van Donselaar, K., Ouwehand, P., 2004. How to use aggregation and combined forecasting to improve seasonal demand forecasts. International Journal of Production Economics, 90 pp. 151-167.

Deleris, L. A., Elkins, D., 2004. Analyzing Losses From Hazard Exposure: A Conservative Probabilistic Estimate Using Supply Chain Risk Simulation, *Proceedings of the Winter Simulation Conference*.

Gaonkar, R., Viswanadham, N., 2004. A Conceptual and Analytical Framework for the Management of Risk in Supply Chains. *Proceedings of the IEEE lnternational Conference on Robotics & Automation*, New Orleans.

Haywood, M., Peck, H., 2003. Improving the management of supply chain vulnerability in UK aerospace manufacturing. *Proceedings of the 1st Euroma/POMs Conference*, pp.121 – 130.

Hopper, S., Beck, M., 2004. Supply Chain Risk: A Global Automotive Industry Viewpoint. *International Corporate Rescue*, 1(4), pp. 23-26.

Lee, H. L., Padmanabhan, V., Whang, S., 1997. The Bullwhip Effect in Supply Chains. *Sloan Management Review*, 38(3), pp. 93-102.

Longo, F., Bruzzone, A. G., 2005. Modeling & Simulation applied to Security Systems. *Proceedings of the Summer Computer Simulation Conference*, pp. 183-188.

Longo, F., Massei, M. 2008. Advanced Supply chain Protection & Integrated Decision support System. *Proceedings of the Asian Modeling Symposium,* Kuala Lumpur (Malesya).

Longo, F., Mirabelli, G., 2008. An Advanced Supply Chain Management Tool Based on Modeling & Simulation, *Computer and Industrial Engineering*, 54(3), pp 570-588.

Longo, F., Mirabelli, G., Viazzo, S., 2005. Simulation and Design of Experiment for analyzing security issues in container terminals. *Proceedings of the International Workshop on Modelling and Applied Simulation.*

Manson-Jones, R., Towill, D., 19989. Shrinking the supply chain uncertainty cycle, *Control*, pp. 17-22.

Merriam-Webster Dictionary: resilience. Available from: http://www.bartleby.com/61/

Mirabelli, G., Papoff, E., Viazzo, S., 2005. Conceptual Model for Analysis of Costs/Risks/Quality within Railway Activities. *Proceedings of the International Workshop on Harbour Maritime & Multimodal Logistics Modelling & Simulation.*

Nagurney, A., Matsypura, D., 2005. Global supply chain network dynamics with multicriteria decision-making under risk and uncertainty. *Transportation Research*, Part E, 41(6), pp. 585-612.

Pai, R. R., Kallepalli, V. R., Caudill, R. J., Zhou, M., 2003. Methods Toward Supply Chain Risk Analysis Systems. *Proceedings of the International Conference on Man and Cybernetics*, 5, pp4560 – 4565.

Peck, H., Juttner, U., 2002. Risk Management in the supply chain. *Focus*, pp. 18-200.

Sheffi, Y., 2005-a. Building a Resilient Supply Chain *Harvard Business Review*, 1(8), pp. 1-4.

Sheffi, Y., Preparing for the Big One, 2005-b, *IEE Manufacturing Engineer*.

Sheffi, Y., 2006. Resilience reduces risk. *The Official Magazine of The Logistics Institute*, 12(1), pp. 13-14.

Sheffi, Y., Rice, J., 2005. A supply chain view of the Resilient Enterprise, *MITSloan Management Review*, 47(1), pp. 41-48.

Stenger, A. J., Ganeshan, R., Boone, T., 2000. The integration aspect of Supply Chain Management: a framework and a simulation. *Supply Chain Management: innovations for education, POMS Series in Technology and Operations Management* 2, pp. 141-156.

Sun, C., Yu, H., 2005. Supply Chain Contract under Product Cost Disruption. *Proceedings of the International Conference on Services Systems and Services Management*, 1, pp. 708 – 711.

Suo, H., Jin, Y., 2004. Supplier-Retailer Contracting Under Asymmetric Risk Attitude Information in Supply Chain. *Proceedings of the 2004 IEEE International Conference On Networking, Sensing & Control*.

Understanding Supply Chain Risk: A Self Assessment Workbook, 2003. *LCP Consulting and Centre for Logistics and Supply Chain Management, Cranfield school of Management*.

Wu, T., Blackhurs, J., Chidambaram, V., 2006. "A model for inbound supply risk analysis", (2006) Computers in Industry.

Zotteri, G., Kalchschmidt, M., Caniato, F., 2005. The impact of aggregation level on forecasting performance. International Journal of Production Economics, 93-94 pp. 479-491.

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