MANAGING RISKS IN NEXT GENERATION SUPPLY CHAINS: A SYSTEMS APPROACH

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ABSTRACT
Supply chain risk management follows three basic processes to manage supply chain risks: Identify, Assess and Mitigate. This paper considers a systems perspective towards managing these risks. It presents variables that may affect Next Generation Supply Chains and applies a System dynamics modelling approach (Oehmen, et. al. 2009) towards depicting the causal linkages of these variables with future supply disruptions. To understand the interdependencies within these factors and the risk propagation on account of these factors it was decided to adopt a systems perspective. This perspective is based upon application of a causal loop diagram which considers the interdependencies between the factors affecting next-generation supply chains. The causal linkages between the variables are then highlighted with regards to the supply chain process and the nodes, and the causes of future risks are identified.

INTRODUCTION
The global business environment today is influenced by financial instability, increased outsourcing, mergers, new technologies, e-business, shorter time-to-market, reduced product lifecycle, make-to-order strategies, pull systems, uncertainty, thus forcing organizations to adopt new ways of doing business (Stefanovic *et al*., 2009). Competition today implies that products and services must be improved not only on the basis of Quality, Lead time and Cost, but also on the basis on environmental sustainability, ethical norms, etc. in order to stay profitable. Next generation supply chain management is expected to not only consider the forward supply chain but also consider equally or even more the reverse supply chain due to its economic impact and stricter sustainable legislations. However, these new approaches to handle supply chains have developed complexity, and uncertainty and may also lead to disruptions. Supply chain disruptions affect not only the cost to the supply chain stakeholder, but also their risk profile (risk-return trade-off). In order to handle uncertainty regarding supply chain disruptions, the stakeholders need to utilise various operational risk-management tools and techniques, and may also design risk information-sharing contracts. This paper considers a systems perspective to understand the implications of next generation challenges for supply chains, the associated risks and provide insights into managing the risks.

A supply chain consists of numerous links interconnecting vast networks and these links are exposed to various operational risks as well as disruption risks (Craighead *et al.,* 2007) Operational risks are referred to inherent uncertainties such as uncertain customer demand, uncertain supply and uncertain cost whereas disruption risks are referred to major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, volcanoes, terrorist attacks (Tang, 2006). Supply chain risk management consists of four management processes:
(1) Identifying the risk sources and drivers
(2) Evaluating and assessing the risks
(3) Mitigating risks within the supply chain
(4) Controlling risks by continuous process.

Implementing the above mentioned risk management process; we identify risks for next generation supply chains by using systems thinking. Applying the system of systems concept to specific supply chains, the supply chain network is represented in terms of nodes and connectors with their interrelations.

LITERATURE REVIEW

The application of System Dynamics modelling to supply chain management has its roots in Industrial Dynamics (Forrester, 1961). The supply chain flows often create important feedbacks among the partners of the chain, thus making System dynamics (SD) a well-suited modelling and analysis tool for next generation supply chain management. System dynamics consists of causal loop diagrams and stock and flow representations of the system. Causal loop diagrams play two important roles in SD. Firstly, they serve as preliminary sketches of causal hypotheses during model development and secondly, they can simplify the representation of a model (Georgiadis *et al.*, 2005). Stock equations define the accumulations within system and flow equations define the flows among the stocks as function of time. The typical purpose of a SD study is to understand how and why the dynamics of concern are generated and then search for policies to further improve the system performance. Here policies refer to the long-term, macro-level decision rules used by strategic level management (Vlachos *et al*, 2007).

Wikner *et al*. (1991) and Towill *et al*. (1992) have simulated different supply chain improvement strategies on demand amplification. Sterman (2000) presents two case studies where SD is used to model reverse logistics problems. Minegishi and Thiel (2000) use SD to understand the complex logistics behaviour of an integrated food industry. They present a generic model and then provide simulation results applied to the field of poultry production and processing. Pierreval (2007) provides a continuous simulation approach to study a French automotive company. Similarly, a SD model for capturing dynamic capacity planning for the remanufacturing process in a reverse supply chain is also developed (Vlachos, 2007). Oehmen *et al* (2009) have attempted a system oriented modelling approach to develop two supply chain models, to determine causes and effects of supply chain risks. From the literature it is observed that, in the supply chain risk management domain only a few attempts are made to understand the risks using a systems approach.

Supply chain risks are potential disruptions associated with inter-organisational logistics, caused by the inherent process or external sources that negatively impact the objectives of the logistics network (Juttner *et al*. 2003). The literature suggests four categories of risks: supply, demand, operational, and security risks (Christopher and Peck, 2004; Manuj and Mentzer, 2008) similarly, Ghoshal (1987) has classified risks as:

- *Macroeconomic risks* associated with significant economic shifts in wage rates, interest rates, exchange rates, and prices
- *Policy risks* associated with unexpected actions of national governments
- *Competitive risks* associated with uncertainty about competitor activities in foreign markets
- *Resource risks* associated with unanticipated differences in resource requirements in foreign markets.

Chopra and Sodhi (2004) classify supply risks as disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory and capacity. There are several other classifications of supply chain risks in literature (Sinha *et al*, 2004; Finch, 2004; Kleindorfer and Saad, 2005; Tang, 2006; Tang and Tomlin, 2008). Next generation supply chain managers need to consider the degree of complexity in their various global supply chains, and then classify risks to define their mitigating strategies.

FACTORS AFFECTING NEXT GENERATION SUPPLY CHAINS

Information and Communication technology (ICT) and sustainability concerns may be the factors which will affect Next generation supply chains. Based on an extensive literature survey, the identified issues for next generation supply chain are represented below:

1. Environmental regulations
2. Information and communication technology
3. 3PL/4PL Logistics service
4. Global market
5. Customer expectations

6. Skills shortage

These issues will feed as input to System Dynamics modelling process to identify impact of these issues on risk assessment parameters within a supply chain. For assessment of risk the identified parameters are quality, delivery performance, cost, environmental initiatives, customer service and technical expertise.

SYSTEMS THINKING

The systems perspective adopted in this research is one of causal modelling. It focuses on understanding how the physical processes, information flows and managerial policies interact so as to create the dynamics of the variables of interest. Complex systems like supply chains are characterized by having large number of dimensions, nonlinear models, strong interactions, volatile parameters, time delays in dynamic structure (Jamshidi, 1983). Supply chain is similarly such a complex system consisting of a complex network of stakeholders and their dynamic interrelationships.

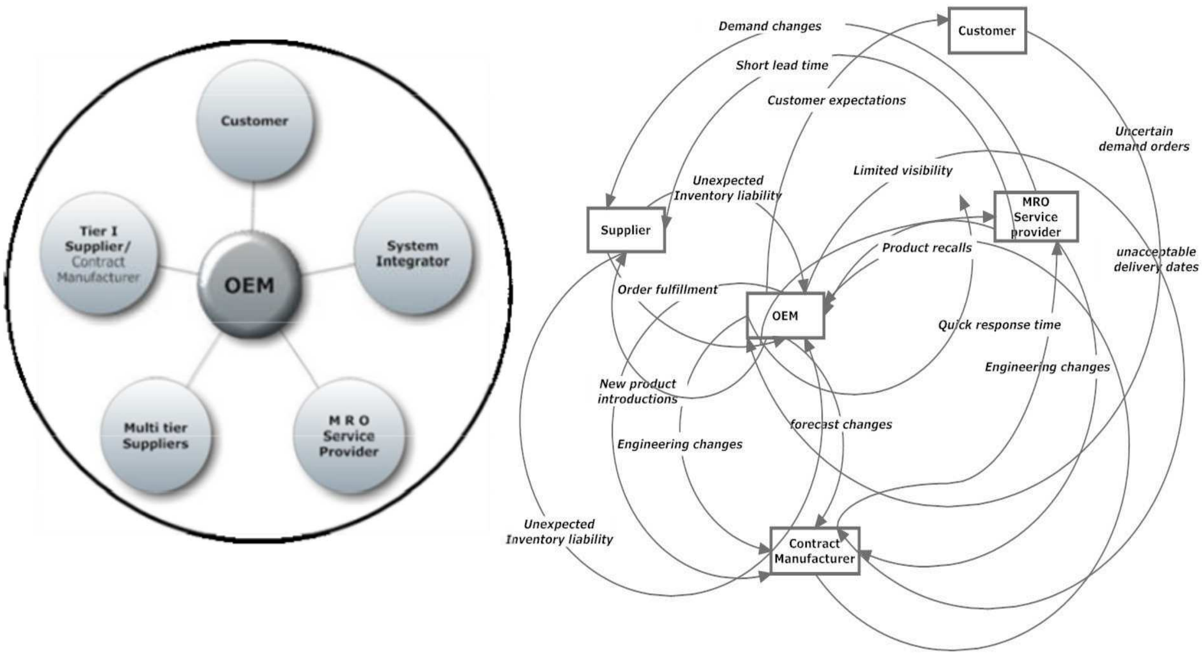


Figure 1 Typical supply chain network links from a systems perspective

For understanding a supply chain, we follow one defined by Kotov (1997) as large scale concurrent and distributed systems that are comprised of complex systems. A supply network/ chain is made up of various entities and nodes in the chain which are working together to achieve one single task, which is providing the final consumer/ customer the required product or service. The optimisation of one part of the chain doesn't necessarily provide an optimised supply chain. The various entities have to be considered together from the perspectives of the interdependencies and the dependency on time to achieve the desired output and thus to make sure that the flow is not disrupted. Hence, the analogy of using a 'Systems of Systems' approach to understand supply chains. Figure 1 represents the system of systems approach to a typical aerospace supply chain network showing the hub and spoke structure of supply chain system and interrelating network links within supply chain entities. The figure presents the aerospace supply chains as a complex network of entities from the perspective of inter-related risks which can cause the flow to disrupt.

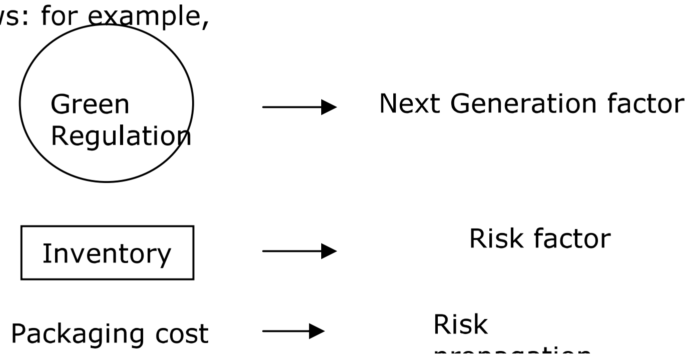
System dynamics is effective for the study of the important flows of products or components through the main production areas of the network, rather than a detailed study of the flow of each product through the set of resources available in the network. System Dynamics (SD) is commonly used for analysing complex, dynamic, uncertain

behaviour of supply chain network and to capture transient effects of flows (material, Information, Financial) in supply chain. SD provides valid description of real processes and integrates human with process and tools.
Based on our understanding, following are key characteristics of SD modelling:

- Captures dynamic / stochastic behaviour
- Ability- Holistic view of system
- Integrates people, process & tools
- Feedback/Inter-relationships of system
- Compatibility-Mental model to computer model
- Early warning for potential risks
- Tool for structured development process

RESEARCH METHODOLOGY
The research was conducted in two phases. In the first phase an extensive literature review was conducted to understand the factors that would affect next generation supply chains. It was also necessary to understand how these factors would lead to risk propagation through the supply chain. The assumption was that all the identified factors will lead to some risk in the supply chain. To understand the interdependencies within these factors and the risk propagation on account of these factors it was decided to adopt a systems perspective. This perspective is based upon application of a causal loop diagram which considers the interdependencies between the factors affecting next-generation supply chains. The causal linkages between the variables are then highlighted with regards to the supply chain process and the nodes and causes of future risks are identified. Using the causal loop diagram, a risk framework is developed for next generation supply chains showing the impact of the risk. This is checked with some instances of risk propagation within the aerospace sector. It was decided to assess the effect of each individual factor taking into account the risks associated with the factor using a system dynamics simulation model. However, this was not successful and the next stage of the research will endeavour to create a simulation framework for simulating the risks associated with the risk factors.

NEXT GENERATION SUPPLY CHAIN RISK VARIABLES: CAUSAL RELATIONSHIP
Causal loop diagrams are the basis on which the SD model is built. They depict, graphically, the interactions and cause-and-effect relationships among the different system parameters (Lertpattarapong, 2002). During the model development, Causal loop diagrams serve as preliminary sketches of causal hypotheses and they can simplify the representation of a model. The structure of a dynamic system model contains stock (state) and flow (rate) variables. Stock variables are the accumulations (i.e. inventories), within the system, while flow variables represent the flows in the system (i.e. order rate). The model structure and the interrelationships among the variables are represented by causal loop diagrams. Figure 3 shows the causal relationship of identified next generation supply chain issues with risk assessment parameters. The representations are as follows: for example,



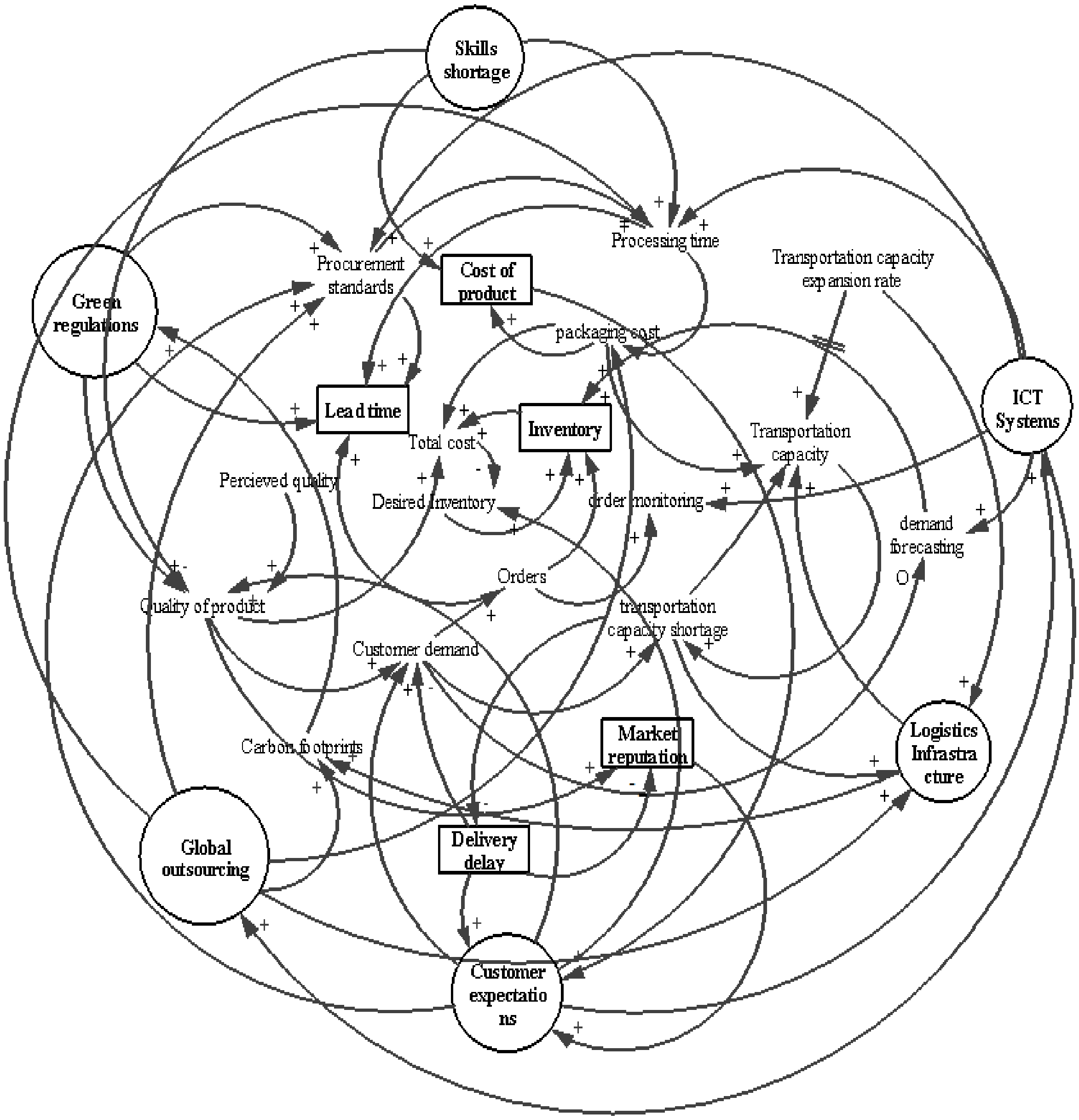


Figure 3: Causal loop diagram for next generation supply chain risks

With reference to the causal model, it can be inferred that this is not complete. Supply Chains are dynamic and as factors change, the risk parameters will modify and propagate. It is important to get a perspective to initially understand the system and then create the capability to dynamically modify it. From the causal loop diagram above, the risk propagation is derived in a risk framework as shown in figure 4.

Applying, the framework to some recent cases in the aerospace sector, it can be seen that the propagation of risk will lead to an increase in total costs, project delays and loss of reputation. This is shown in table 1. It seems fairly generic; however it is important to note that whatever the factors affecting next generation supply chains, the final impact will lead to issues of cost delays and reputation. This may modify sectorally, and the essence of further research would be to assign weights to each impact based on the sectoral perspective.

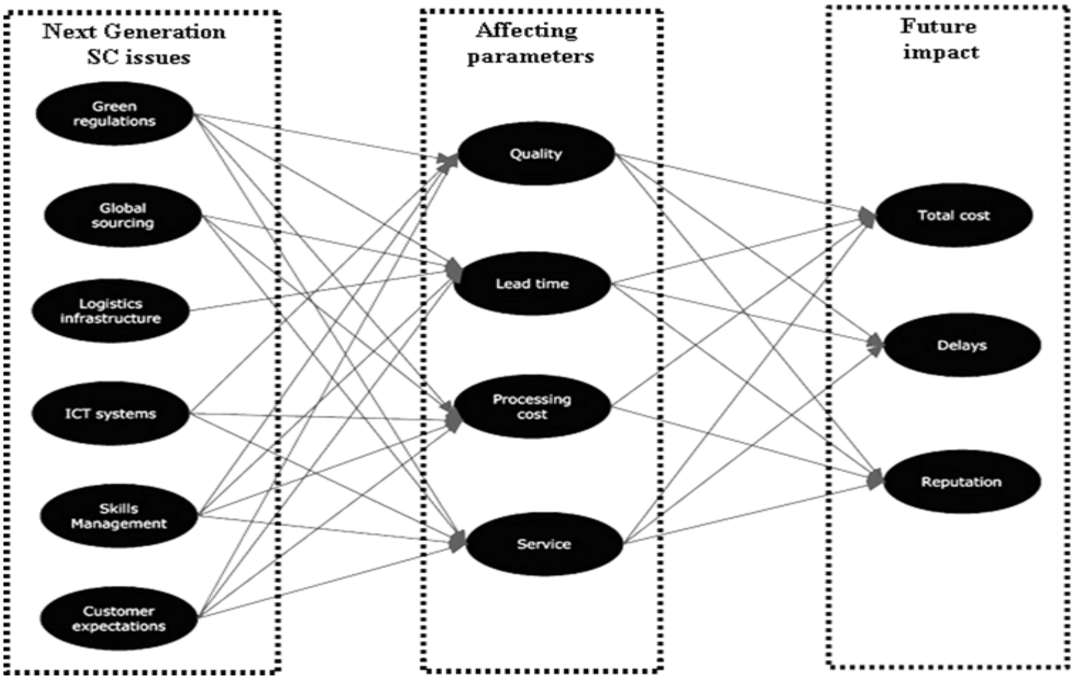


Figure 4: Next generation supply chain risk model

Industry	Supply Chain Disruption	Risk Impact
Airbus A380 (2005)	1) Distributed Integration dependencies among manufacturing sites and suppliers 2) Design configuration management problems (CATIA V4/V5)	1) Mismatch of electrical harness between designed and physically appeared routing on aircraft. 2) **Costly delays** for two years.
Boeing 787 (2006)	1) Failure of assemble to order manufacturing strategy 2) Failure by global supplier network to meet targets	1) Problems with spare parts led to **delays** up to 2 years. 2) **Financial loss** due to cancellation of orders. 3) **Reputation loss**
JSF F-35 Lockheed Martin (2010)	1) Development is being done concurrently with early production. 2) National shortage of professionals leading to longer flight test program.	1) JSF F-35 **delays** up to 2015 to US Air Force 2) Delays resulting in **heavy cost increases** to JSF program partners.

Table 1: some instances of supply chain risk propagation in the aerospace sector

CONCLUSION

The research approach for the paper is based upon application of systems engineering techniques to understand next generation supply chains and its use for managing various risks associated within the supply network. Factors affecting next generation supply chains are identified. A Causal loop diagram is depicted which considers the causal linkages between the factors and highlights with regards to the supply chain process, the nodes and causes of future risks. In this paper, the SD modelling approach identifies influential risk parameters for next generation supply chains which further would be mitigated through different risk management strategies as a future work towards developing a SCRM toolkit. The paper thus presents a new perspective towards using systems thinking to manage future supply chain risks. Simulating the complete model requires setting of dependence parameters/equations which is complex due to non-availability of data for a simulation model. An attempt was made to simulate the model using Vensim simulation software considering a part of the causal loop by taking few assumptions in developing parameters/equations. However, using simulation to study the problems involving supply chain disruptions has its problems and challenges. These challenges are most evident in four areas like, **Describing** and **modelling** the events triggering the supply chain disruption for example how to describe SCD and its associated critical traits and location of disruption and **identifying** and **setting** approximate policies and parameters (Zsidisin and Ritchie, 2008). Hence in this paper we have restricted the scope of research up to identifying risk factors that influence next generation supply chain and further investigation would be carried into possibilities of developing simulation model for risk assessment and designing mitigation strategies as a part of a SCRM toolkit.

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