CONCEPTUAL MODEL OF SUPPLY CHAIN NODE FOR SIMULATION BASED RISK ANALYSIS

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ABSTRACT
The Supply Chain comprising of distribution centres, plants, terminals and stores in the product flow, and Information and Communication Technologies platforms in the information flow face a lot of risks in today's competitive world. As SCs are highly complex dynamic multi-state systems, such systems as well as their individual nodes are exposed to numerous random factors in the form of various risks, which include natural disasters, terrorism, cyber attacks, credit crunch, and what is more is the impact of demand risk due to optimistic forecasts that turn out to be a disaster due to organizations' ineffective and inefficient information flow. These risks could yield to a drastic loss in productivity, revenue, competitive advantage, profitability etc, if not managed appropriately. This article discusses the risks typical to the supply chain as well as the conceptualization of risks for subsequent simulation-based analysis. In addition, the development of a generic conceptual model of a retail node is described and relevant performance measure indicators are introduced.

Keywords: resilience, simulation, risk analysis, supply chain

1. SUPPLY CHAIN NODES

Before analysing the supply chain (SC) nodes, it is necessary to define the supply chain itself.

1.1. Defining the Supply Chain

Over the past 50 years, the supply chain has greatly evolved from traditional to modern innovative companies that are actually outsourcing almost all the processes in the supply chain unlike the traditional companies that were wholly and solely responsible for supplies, manufacturing and distribution. This has somehow affected the definition of the supply chain and currently it has many definitions consisting of overlapping terminology and meanings. Hence, several authors have come up with different definitions that tend to overlap in many cases with the supply chain being defined, for example, as 'a group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-customers' (Lu 2011), or 'a general description of the process integration involving organizations to transform raw materials into finished goods and to transport them to the end-user' (Pienaar 2009). Furthermore, it is also defined as 'a sequenced network of business partners involved in production processes that convert raw materials into finished goods or services in order to satisfy the consumers' demand' (Mensah and Merkuryev 2012).

Although the aforementioned definitions lacks the terminology 'nodes and links', they do refer to them indirectly. The authors have discussed nodes and links below.

1.2. Nodes and Links

Nodes and Links build up the supply chain where nodes are factories, distribution centres, warehouses, stores that are engaged in product flow. As far as the information flow is concerned the nodes are mainly Information and Communication Technologies (ICT) platforms. In addition, nodes can also be described as fixed spatial points where goods are stored or processed. The links which are mainly roads, rails, waterways, airways etc, represent the transportation network and connect the nodes. Figure 1 below illustrates an example of a supply chain with its nodes and links.

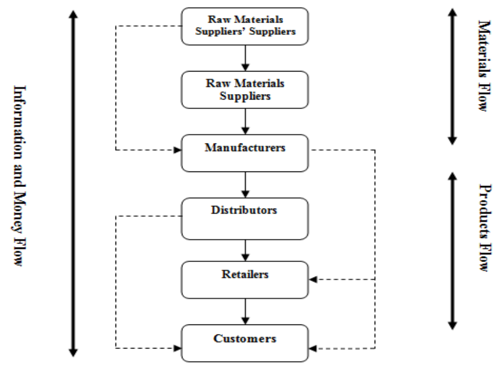

Figure 1: Supply Chain Nodes (Mensah and Merkuryev 2013)

With reference to Figure 1, the nodes represented in boxes include raw materials suppliers' suppliers, raw materials suppliers, manufacturers, distributors, retailers and customers are linked by arrows. The nodes are in stages within the upper stream and lower stream of the supply chain. All of these stages involve the 'flow of materials, information and money through a business network, all the way from the suppliers to the customers' (Croker 2003) and vice versa.

The links are also illustrated in Figure 1 connecting the nodes by arrows. For example, in the upper stream of the supply chain, materials flow from the raw materials suppliers' suppliers to the raw materials suppliers and then down to the manufacturers through transportation network consisting of roads, rails, waterways, airways etc. After production, the products flow from the manufacturers to the distributors that distributes to the retailers through a network of transport. The retailers finally supply the customers in stores. However, the supply chain does not end there as an ICT platform communicates the flow of information, products, money and materials between the upper and lower limits of the supply chain. As the network within the nodes and links is complex, any part of the supply chain is vulnerable to risks that could disrupt the whole system. The risks are discussed in the next section.

2. RISKS IN THE SUPPLY CHAIN

'In today's uncertain and turbulent markets, supply chain vulnerability has become an issue of significance for many companies' (Christopher 2004, Peck 2004).

Risks including natural disasters, terrorism, cyber attacks, credit crunch shrinking product lifecycles, volatile and unpredictable markets and many more, could yield to a drastic loss in productivity, revenue, competitive advantage, profitability etc, if not managed appropriately. As the numbers of threats that can undermine a supply chain are now greater, organizations are facing greater challenges in managing risks (Sheffi 2005). According to the results of the 4th Annual Survey of the Business Continuity Institute in Supply Chain Resilience in 2011, where more than 550 organizations from over 60 countries were surveyed, 'Supply chain incidents led to a loss of productivity for almost half of businesses along with increased cost of working (38%) and loss of revenue (32%)' (The Business Continuity Institute 2011).

Another survey by the Independent Risk Consulting Company, Protiviti, about Understanding Supply Chain Risk Areas, Solutions, and Plans (Protiviti 2013), highlights that the risks in operational supply chain are many. Hence, organizations should therefore be always alert as these risks, could hinder their performances leading to a loss in profits and competitive advantages. These risks are given in bullet points below:

- A variety of supply interruption risks
- Demand and supply planning and integration risks
- Purchase price risks
- Inventory and obsolescence risks
- Regulatory and compliance risks
- Information privacy and security risks
- Customer satisfaction and service risks
- Contract compliance and legal risks
- Process inefficiency risks
- Employee and third-party fraud risks
- Product introduction and cycle time risks
- Human resource skills and qualifications risks
- Project management risks
- Corporate culture and change management risks
- Information integrity

Managing all the above risks is a concern especially in small and middle size organizations. However, the authors have considered a few according to their importance, namely:

- Demand and supply planning and integration risks
- Inventory risks
- Customer satisfaction and service risks
- Information integrity

Taking the retail sector into consideration, today most retailers spend lots of time and money in forecasting where they hope to get the 'right figures' so that their forecasted demand will meet with their actual demand. Unfortunately, in many cases the figures are not accurate. This could be because the retail supply chain in not linked and every node is forecasting for itself. This actually leads to 'retail out-of stock' affecting retailers and their partners. Doherty, Harrop and Martin point out that retail stores are the weakest in the retail supply chain as far as out-of-stocks are concerned. In addition, 'retail store out-of-stocks (usually in the 5 percent to 8 percent range) are indeed much worse than the percentage of out-of-stocks that occur elsewhere across retail supply chains. Even worse, those numbers balloon to almost 15% during promotions' (Doherty, Harrop and Martin 2012).

In the current competitive business world, customers' preferences are dynamic and changes most of the time. Consequently, it is quite challenging to sustain customers' satisfaction as they can easily switch. Developing a platform where constant feedback is obtained from current customers with organizations reacting accordingly whilst trying to gain new customers could be the answer.

Integrity risks occur due to miscommunication and lack of transparencies which can only be dealt with through accurate flow of information, materials, and product along the supply chain as this would ensure visibility, integrity and transparency. All of these are a stepping stone in developing a supply chain resilient strategy which is discussed in the next section.

3. DEVELOPING A SUPPLY CHAIN RESILIENT STRATEGY

3.1. Defining Resilience

Resilient Strategy in the supply chain is a new area that still needs thorough research.

Some research papers have defined supply chain resilience as, 'the ability of a system to return to its original or desired state after being disturbed' (Cranfield School of Management 2003) or 'the ability to bounce back from large-scale disruptions' (Sheffi 2008), where as the dictionary definition of 'resilience' states that it is the ability of a substance to return to its original shape after it has been bent, stretched or pressed (Oxford Advanced Learner's Dictionary 2013).

3.2. Resilient Strategy

As the risks discussed in the former section could disrupt the supply chain if they occur, it is now essential for organizations to have a resilient strategy as part of their strategic plans in order to avoid the occurrence of these risks or if they do occur, organizations would be able to bounce back speedily after disruptions. By planning and implementing lean production, six sigma practices, flexibility and a strong corporate culture, the capabilities to speed up the process of bouncing back after deformation on any part along the supply chain is very possible. This is where the role of ICT in the supply chain is significant as a shared ICT infrastructure consisting of six sigma software, Enterprise Resource Planning (ERP) and Social Intranet Software is implemented. This would facilitate lean production, a strong corporate culture is developed that would engage management and employees on the activities of the organization through online communication and collaboration. This will result in improved services, reduced logistics costs and faster communication between customers and their suppliers. In addition, organizations will also make accurate and quick decisions after deformation of its supply chain that will eventually bounce it back to normal activities in the shortest possible time.

From another perspective, Modelling and Simulation could be used as an application technique to support supply chain design, management and optimization (Longo 2012) as any network of supply chain (Klimov et al. 2010) can be easily represented by a simulation model.

Furthermore, simulation can be used as decision support tool in order to improve the supply chain management, reduce risks and vulnerability (Longo 2012).

4. RETAIL SIMULATION AND RETAIL RISK SIMULATION

Usually the risk concept is discussed in the context of applications of simulation models in finance and insurance. The statement can be proved by the analysis of the publications from one of the most authoritative sources in the field of modelling and simulation – the Winter Simulation Conference (WSC). Only in 2011 the section "Risk Modelling, Assessment, and Applications" arrived in WSC proceedings. This fact reflects the tendency to use simulation in the analysis and mitigation of influence of risk factors on the behaviour of complex artificial systems, e.g. supply chains.

Starting from the 60s of the 20^{th} century many articles were published in the area of supply chain simulation. One of the first researches was famous Jay Forrester Industrial Dynamics introducing a macro level supply chain simulation model and experiments with it. Forrester had described a three-echelon supply chain model and analyzed the impact of demand variations (Forrester 1961). Actually this simulation was the beginning of system dynamics.

In one of the first publications of WSC 1968 in the area of SC modelling, the author described the purpose of modelling, including how far can some of the dynamic instabilities and adaptive patterns can be explained within an abstract simulation model. (Pfaff 1968). The simulation model was used to study the influence of changing consumer demand on the behaviour of all links of the logistics chain. The particular interest is a conceptual model of the retail node of the supply chain, proposed by the author. The experiments were held using different scenarios with multiple demand patterns. The random demand, or demand with rare significant fluctuations that are peculiar for events associated with risks were not investigated.

The same volume of WSC 1968 proceedings contains another paper devoted to SC simulation but using the different concept (Dulchinos and Hill 1968). The simulation model implements a discrete-event approach and is implemented as a micro model with detailed operation description. The input of the lowest level SC node is a random demand for a specific item whilst the outputs are orders from the wholesaler and deliveries to the consumers.

Since these studies, the use of simulation analysis of supply chain functioning continues to develop in these traditional – system dynamics and discrete event approach – directions. Recently, the agent-based modelling in this area has become topical.

5. CONCEPTUAL MODEL OF RETAIL NODE IN RISKY ENVIRONMENT

Accepting the idea of a conceptual model as 'a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model' (Robinson 2004), one introduces the conceptual model of a retail node for the purposes of simulation both as a single, separate object of interest and as a node of a complex SC. The conceptual model forms the hypothetically complete description of the original system (Becker and Parker 2011). Conceptual modelling is the abstraction of a simulation model from the real world system that is being modelled (Robinson et al. 2012).

In this context, the objective of creating a SC simulation model is getting a tool for assessing the performance of the supply chain in the process of long, medium or short-term decision making. The inputs of the simulation model of a retail node of SC are deliveries from the wholesalers, consumer demand and outputs – orders to the wholesalers, deliveries to the consumers or sales, the main state variable – inventory. Additional state variables and performance measures may be considered, e.g. sales, costs and customer service level. The controllable experimental factors include the order and assortment parameters, customer parameters, inventory management strategy. Uncontrollable experimental factors are unpredictable environmental factors and risk events. As a retail node is a part of a multi echelon supply chain, the model should implement an information feedback between nodes of different levels. A characteristic feature of each model is the mechanism of time advance, which allows us to classify the computer model as a model system dynamics or discrete-event simulation model. The choice of an approach depends from the purpose of a concrete project.

Figure 2 provides an outline of the reasonable content of a conceptual model of a retail node according the approach suggested by Robinson (2004). The more detailed content is determined by the goal of the particular research. The simulation model is accepting the inputs (on the left) – experimental data and events and provides outputs (on the right) – performance measure estimates.

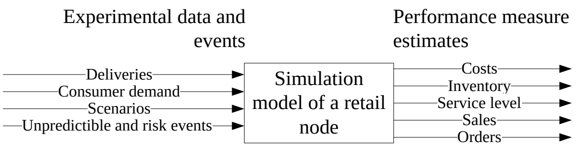

Figure 2: Conceptual Model Content of a Retail Node

The modelling objectives are stated by the problem and define inputs, outputs and the content of the model. The simulation model provides data for statement whether modelling objective is achieved or not. In case of failure, the reasons of failure are revealed. As risks in a supply chain should be measured, valued and managed by costs, the performance measures may be expressed in monetary units. For example, Klimov et al. (2010) introduces a case study where only two types of possible local costs are considered namely, inventory holding costs and backordering costs. Such choice gives possibility to analyze both inventory management efficiency and customer service level. The risky environment in this concept may be simulated using scenario approach and risk events simulation, using approaches together or separately.

Supply chain risks may be categorized as external or internal ones. The retail node is affected by process risks internal to the company, demand and supply risks external to the company and internal to the supply chain, and environmental risks external to the supply chain (Longo and Ören 2008). The goal of the model development is to provide computer experiments to study the adaptive behaviour of the SC nodes and to provide relevant information to decision makers.

After the identification of the risk factors, for simulation purposes we need to (a) describe their variability, (b) probability of occurrence, (c) the set of nodes and arcs that they affect and (d) the duration of the disruption that they cause (Deleris and Erhun 2005). This approach incorporates external events to evaluate uncertainty in supply networks.

The randomness of the demand itself may be interpreted as risk: "risk is any uncertainty that affects a system in an unknown fashion" (Klimov et al. 2010). The impact of this risk factor on the whole SC may be one of the causes of the Bullwhip effect (Longo and Ören 2008). Unnecessary costs associated with demand risks are observed when the demand exceeds the supply and the customers are disadvantaged or when the supply exceeds the demand, the company stockholders are disadvantaged (McGarvey and Hannon 2003).

An example list of risks associated with customers and customer demand is provided by Bendža (2014). The list is based on the study of a business process of a small Latvian retail enterprise. Only high end extreme level risks are included into the list:

- Return of an online purchase
- Latvia's economic crisis of 2008/2009 effects
- difficulty to forecast the demand accurately
- current financial crisis in the United States
- customer failure to pay for the item/s
- decrease of interest in paper format editions
- competitors among other field related retailers

It is clear that some of the risk factors mentioned above are described as events (return or failure event), some as trends (decrease of interest) and some are in "free format". Free format risk factor description should be formalized for the purposes of modelling and simulation using realistic assumptions and simplifications and included or not into the simulation model.

Finally, risk analysis of retail nodes of SC simulation is used to describe the dynamic behaviour of a given supply chain structure and to assess the benefits of supply chain policies, such as inventory policies, taking into account the initial state of the node, and order fulfilment rules and algorithms as well as inventory management strategies.

REFERENCES

Becker, K., Parker, J. R., 2011. *Guide to Computer Simulations and Games.* Hoboken, NJ: John Wiley & Sons.

Bendža K., 2014. *Modeling-Based Risk Analysis of a Small Enterprise*. Master thesis, Riga Technical University.

Business Continuity Institute, 2011. *Supply Chain Resilience 3rd Annual Survey*. The Business Continuity Institute. Available from: http://www.zurich.com/internet/main/sitecollectiondocuments/insight/supply-chain-survey-2011.pdf [accessed 7 July 2014].

Christopher, M., Peck, H., 2004. Building the Resilient Supply Chain. *International Journal of Logistics Management,* 15, pp. 1-13.

Cranfield School of Management, 2013. *Creating Resilient Supply Chains: A Practical Guide*. Cranfield University. Available from: https://dspace.lib.cranfield.ac.uk/bitstream/1826/4374/1/Creating_resilient_supply_chains.pdf [accessed 7 July 2014].

Crocker, J., 2003. *The Supply Chain: Increasing Value through Process Improvement.* Clermiston Consulting Pty Ltd. Available from: http://www.clermiston.com.au/Documents/Supply%20Chain%20Increasing%20Value%20Process%20Imp%20JRC%20Handout%202x.pdf [accessed 10 October 2013].

Deleris, L. A., Erhun, F., 2005. Risk Management in Supply Networks Using Monte-Carlo Simulation. *Proceedings of the 2005 Winter Simulation Conference,* pp. 1643-1649. December 4-7, Orlando (Florida, USA).

Doherty, M., Harrop, J., Martin, A., 2013. *Flowcasting the Retail Supply Chain – Executive Summary*. Available from: http://www.flowcastingbook.com/exec-sum.pdf [accessed 7 July 2014].

Dulchinos, P., Hill, J., 1968. Simulating the Operation of the Logistics System. *Proceedings of Winter Simulation Conference*, pp. 119-129. December 2-4, New York (USA).

Forrester, W. J., 1961. *Industrial Dynamics.* Cambridge, Massachusetts: The M.I.T. Press.

Hannon, B., McGarvey, B., 2003. *Modeling Dynamic Systems for Business Management An Introduction.* New York, NY: Springer.

Klimov, R., Merkuryev, Y., Tolujev, J., 2010. A Theoretical Framework for a Simulation-Based Analysis of Supply Chain Risk Management. In: Ponis, S., editor. *Managing Risk in Virtual Enterprise Networks: Implementing Supply Chain Principles*. Hershey PA, USA: IGI Global, pp. 162-182.

Longo, F., 2012. *Sustainable supply chain design: an application example in local business retail.* Transactions of the Society for Modelling and Simulation International. Available from: http://intl-sim.sagepub.com/content/88/12/1484.abstract [accessed 10 January 2013].

Longo, F., Ören, T., 2008. *Supply Chain Vulnerability and Resilience: a State of the Art Overview.* The University of Ottawa, Faculty of Engineering. Available from: http://www.site.uottawa.ca/~oren/pubs-pres/2008/pub-0806-supplyChain-Italy.pdf [accessed 10 January 2013].

Lu, D., 2011. *Fundamentals of Supply Chain Management.* Frederikesberg, Denmark: Ventus Publishing ApS.

Mensah, P., Merkuryev, Y., 2013. The role of ICT in the supply chain resilience, *Proceedings of the 6-th International Conference on Applied Information and Communication Technologies* (*AICT2013*), pp. 129-135. April 25-26, Jelgava, Latvia.

Oxford Learner's Dictionaries, 2013. *Definition of resilience noun from the Oxford Advanced Learner's Dictionary.* Available from: http://www.oxfordlearnersdictionaries.com/definition/english/resilience [accessed 1 October 2013].

Pfaff, M., 1968. Experiments on an adaptive Computer Model of a Distribution Channel. *Proceedings of Winter Simulation Conference*, pp. 179-188. December 2-4, New York (USA).

Pienaar, W., 2009. Introduction to Business Logistics. Southern Africa: Oxford University Press.

Protiviti, 2013. *Understanding supply chain risk areas, Solutions, and plans. A five part series*. Protiviti. Available from: http://www.protiviti.com/en-US/Documents/Surveys/SupplyChainRiskAreas.pdf [accessed 1 October 2013]

Robinson, S., 2004. *Simulation: The Practice of Model Development and Use.* Chichester, UK: John Wiley & Sons.

Robinson, S., 2012. Tutorial: Choosing What to Model - Conceptual Modeling for Simulation. *Proceedings of Winter Simulation Conference*, pp. 1909-1920. December 9-12, Berlin, Germany.

Sheffi, Y., 2005. *Building a resilient SC. Harvard Business Review*. Supply chain strategy, 1 (8): pp. 1-4.

Sheffi, Y., 2008. *Resilience: What it is and how to achieve it*. Massachusetts Institute of Technology. Available from: http://web.mit.edu/scresponse/repository/Sheffi_Congressional_Testimony.pdf [accessed 1 October 2013].

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